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Kusano et al.

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(45) **Date of Patent: May 25, 2004**

(54) **VALVE TIMING ADJUSTING APPARATUS**

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(73) Assignee: **Denso Corporation**, Kariya (JP)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**[7] **F01L 1/34**

(52) **U.S. Cl.** .... **123/90.17**; 123/90.15; 123/90.12; 464/1; 464/2; 464/160; 92/120; 92/5 L

(58) **Field of Search** .... 123/90.17, 90.18, 123/90.12, 90.15, 90.31; 92/5 L, 69 R, 70, 71, 75, 120–125; 464/1, 2, 160

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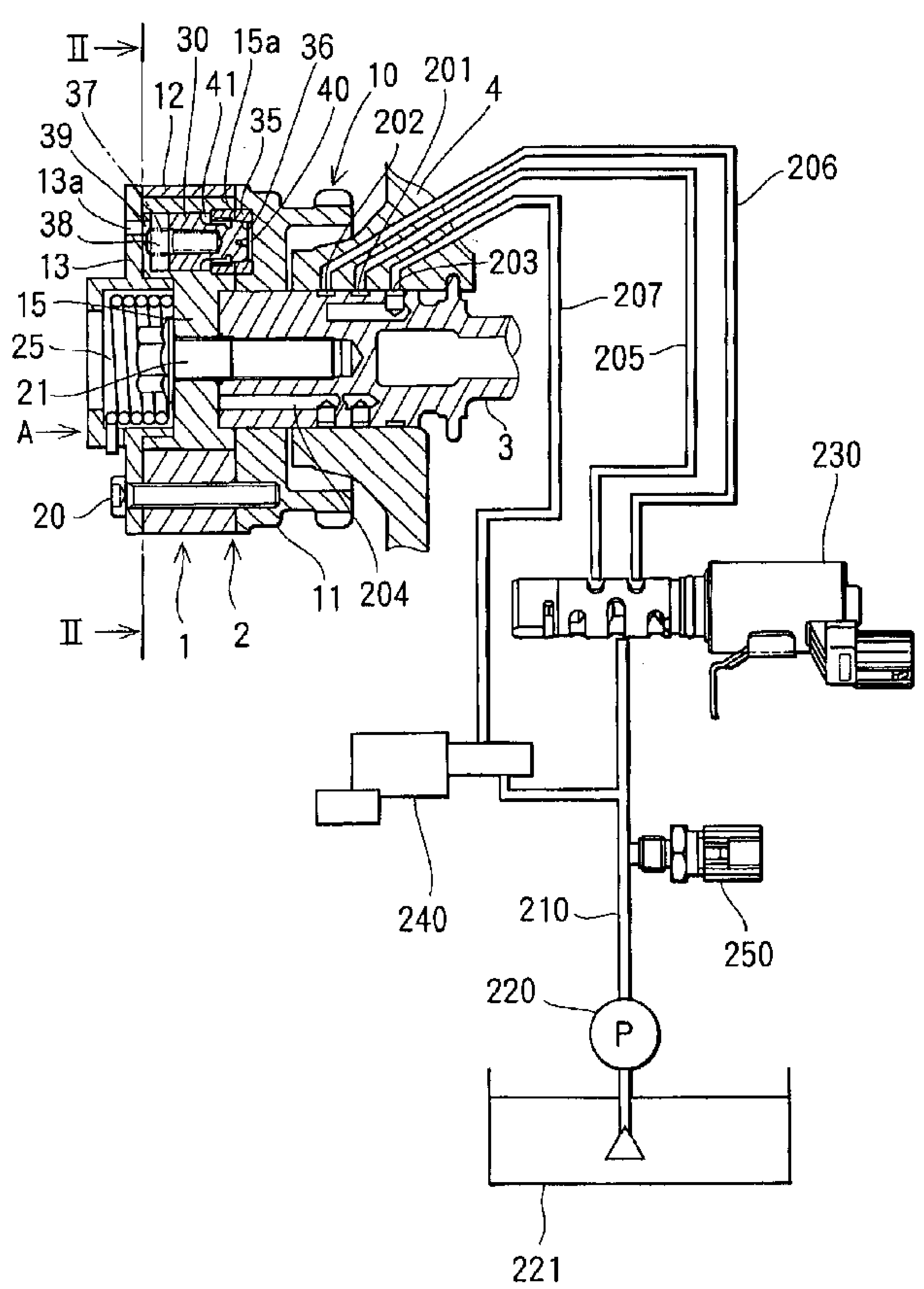
(74) *Attorney, Agent, or Firm*—Nixon & Vanderhye P.C.

(57) **ABSTRACT**

In a valve timing adjusting apparatus, rotating response speed of a vane rotor and a moving speed of a lock piston are changed according to changes of oil temperature and pressure. It sometimes happens that the lock piston passes the fitting hole before the lock piston is fitted in the fitting hole. Timing of actuating a solenoid valve is retard by a given delay time from timing of actuating a spool valve. The given delay time is decided by a map based on sensor signals representing the oil temperature and pressure input to ECU. The given delay time is shorter as the oil temperature increases and longer as the oil pressure increases.

18 Claims, 13 Drawing Sheets



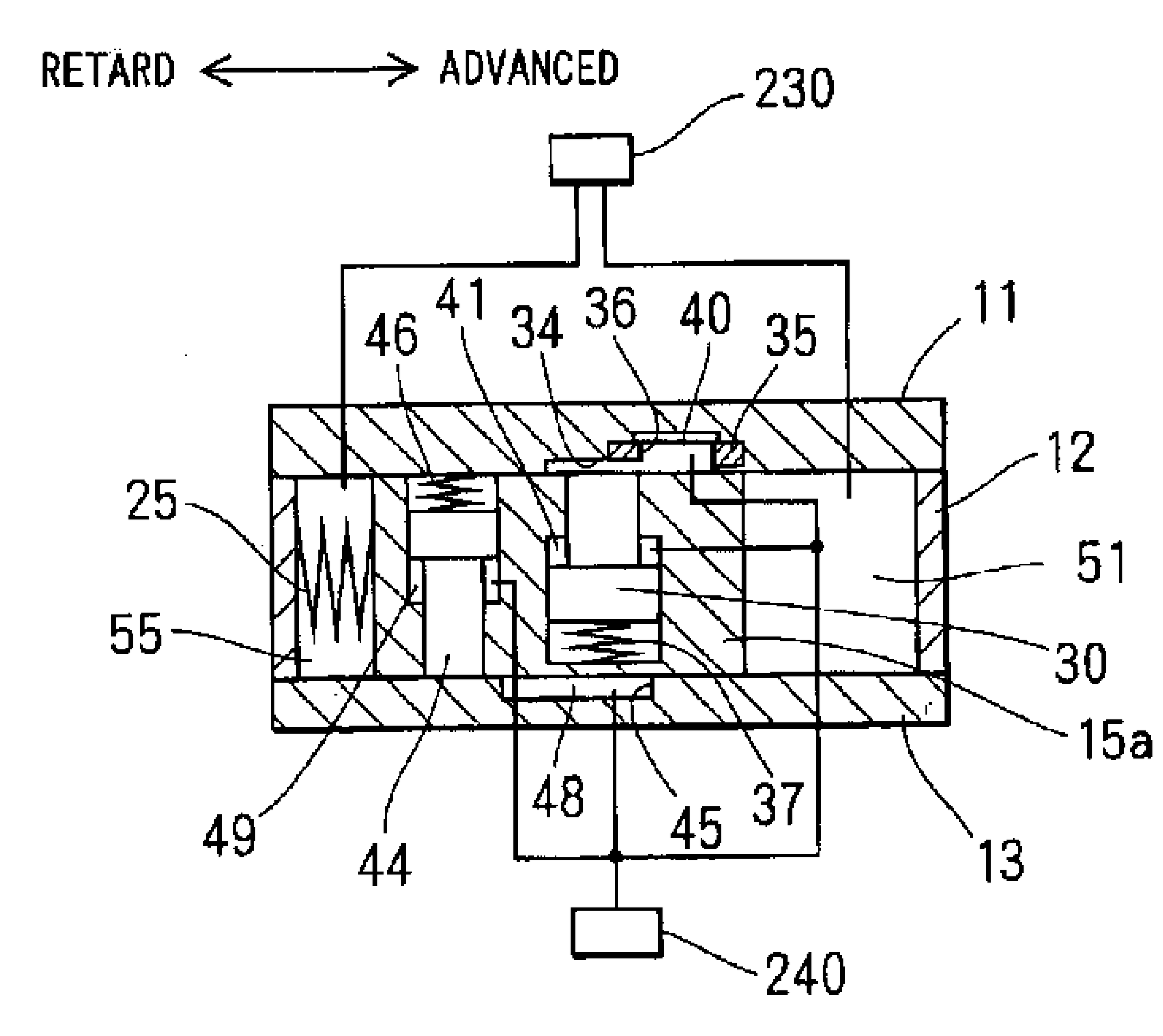


FIG. 1

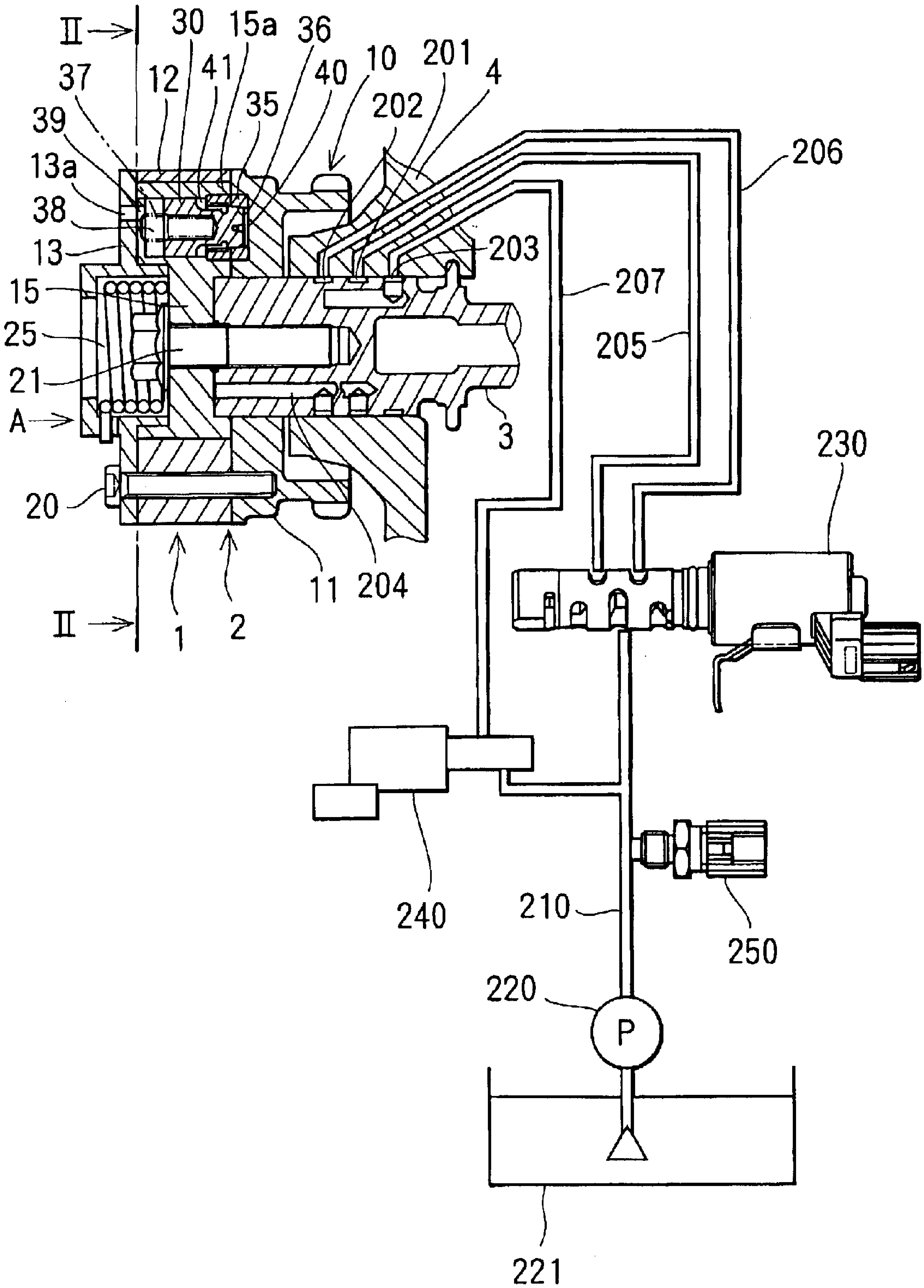

II
30
15a
36
37
12
41
40
10
201
4
39
35
202
206
13a
38
203
13
207
15
205
25
21
A
3
230
20
11
204
II
1
2
240
210
250
220
P
221

FIG. 2

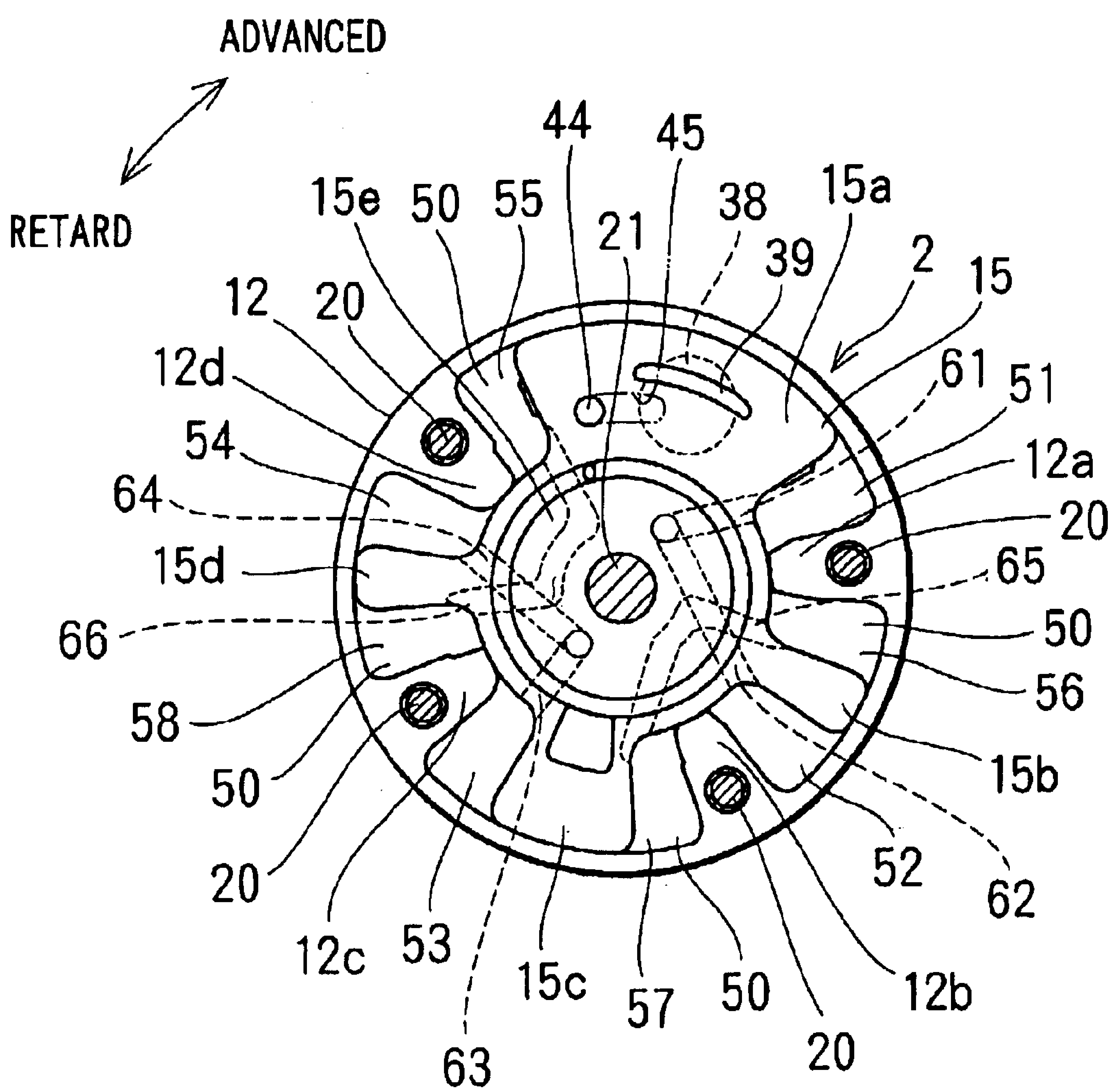
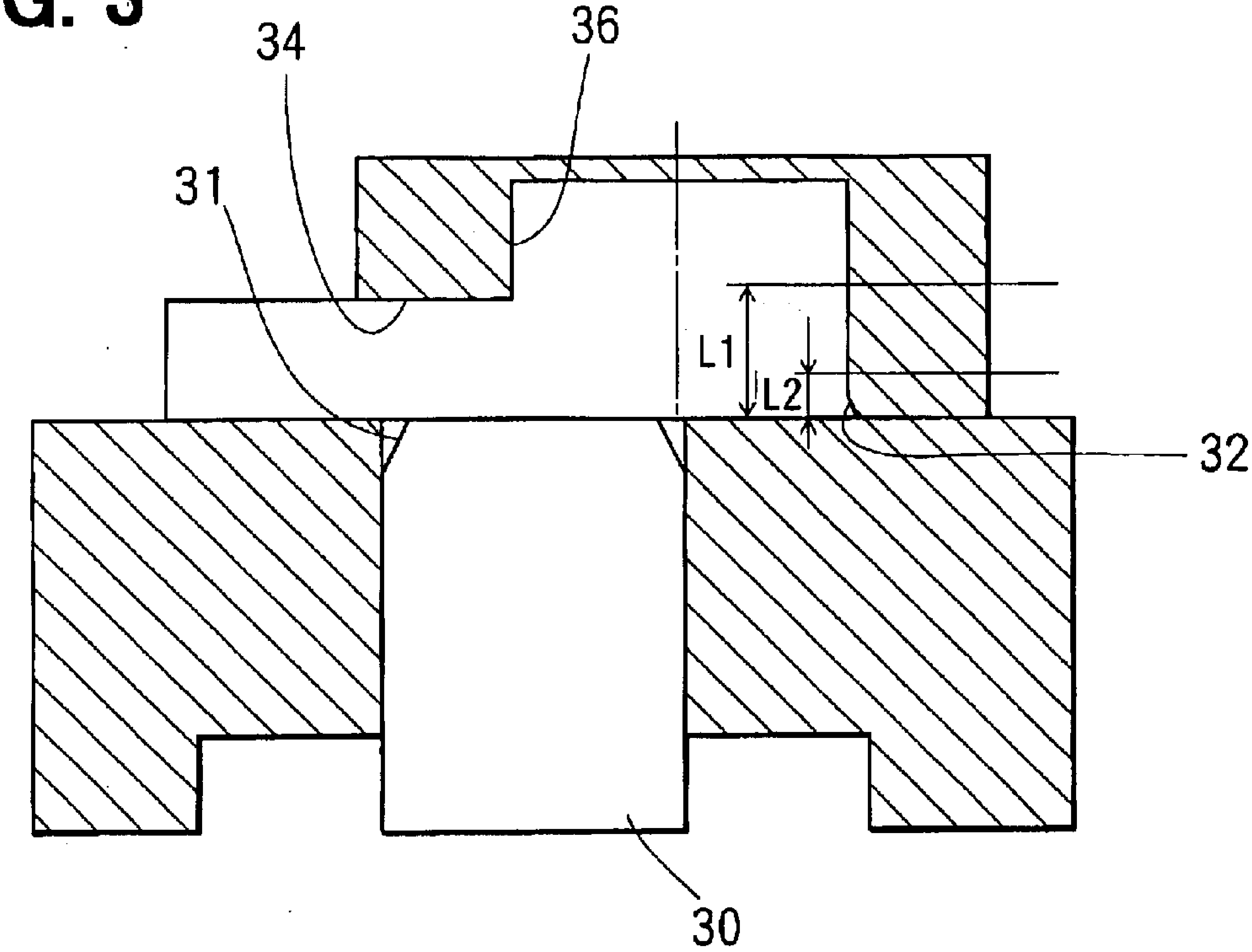
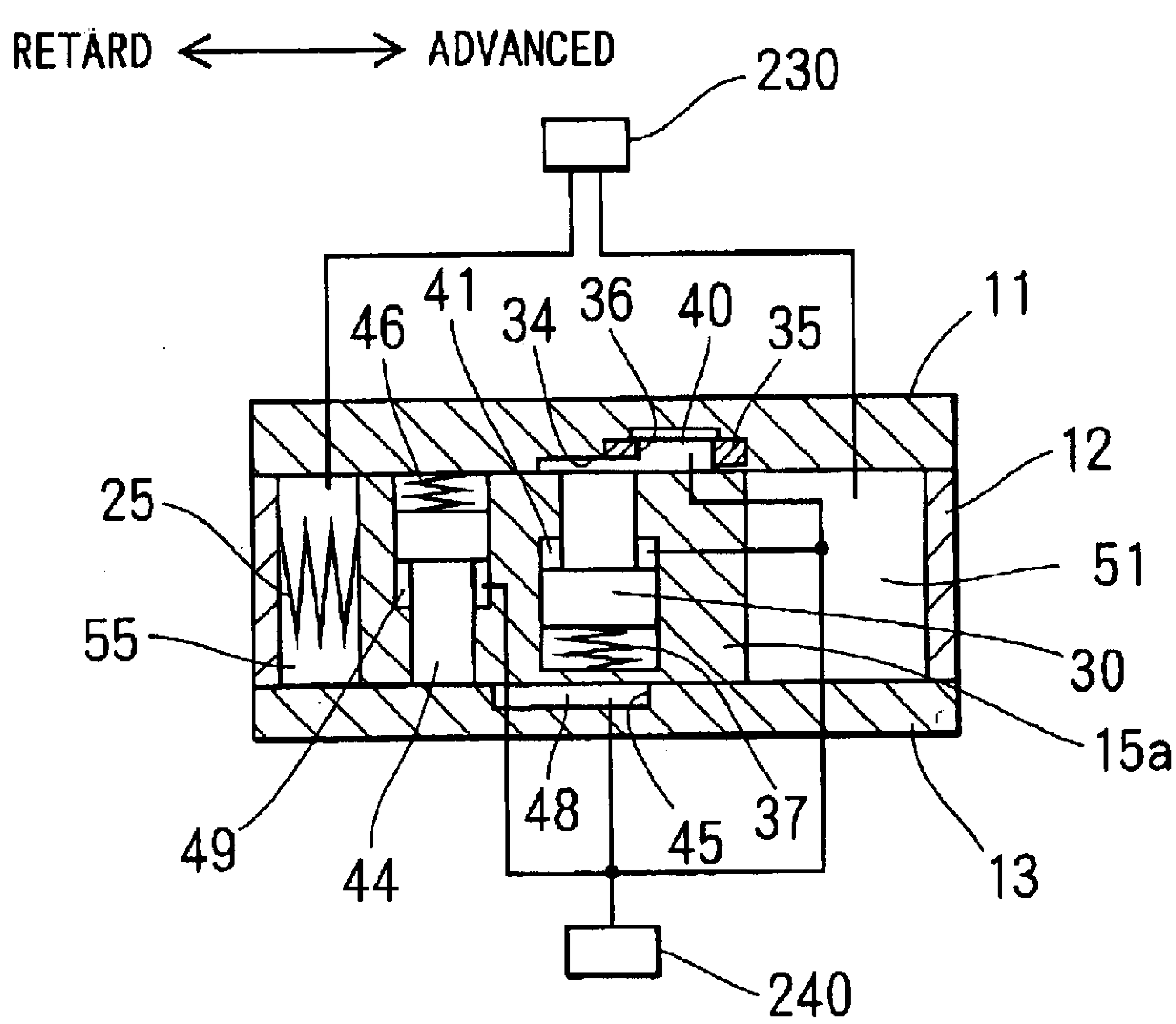

ADVANCED
RETARD
44
45
38
15a
15e
50
55
21
39
2
15
12
20
12d
61
51
12a
54
64
20
65
15d
66
50
56
58
15b
50
20
52
62
12c
53
15c
57
50
20
12b
63

FIG. 3



34
36
31
L1
L2
32
30

FIG. 4



RETARD
ADVANCED
230
46
41
34
36
40
35
11
12
25
51
55
30
15a
49
44
48
45
37
13
240

FIG. 5

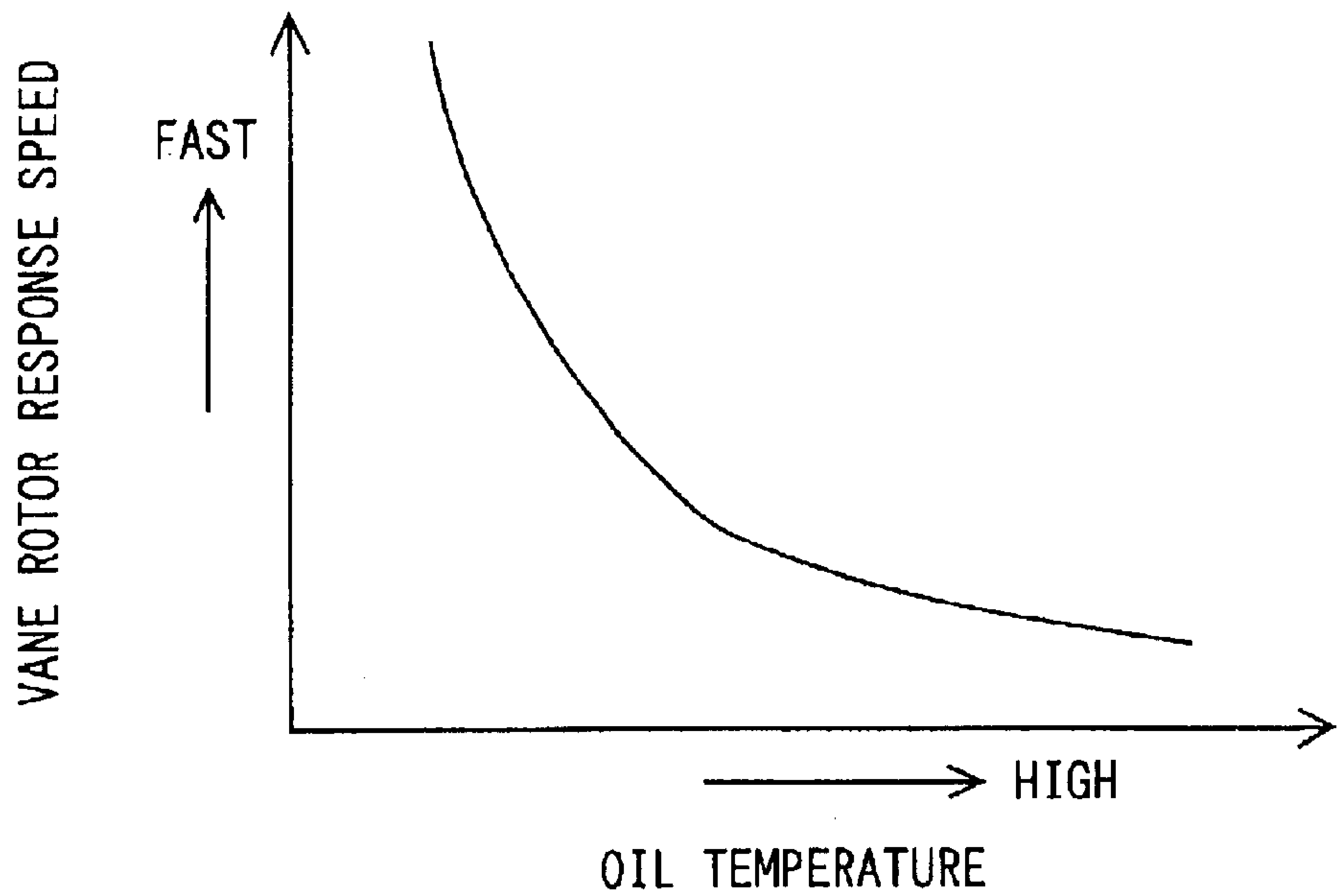

VANE ROTOR RESPONSE SPEED
FAST
HIGH
OIL TEMPERATURE

FIG. 6

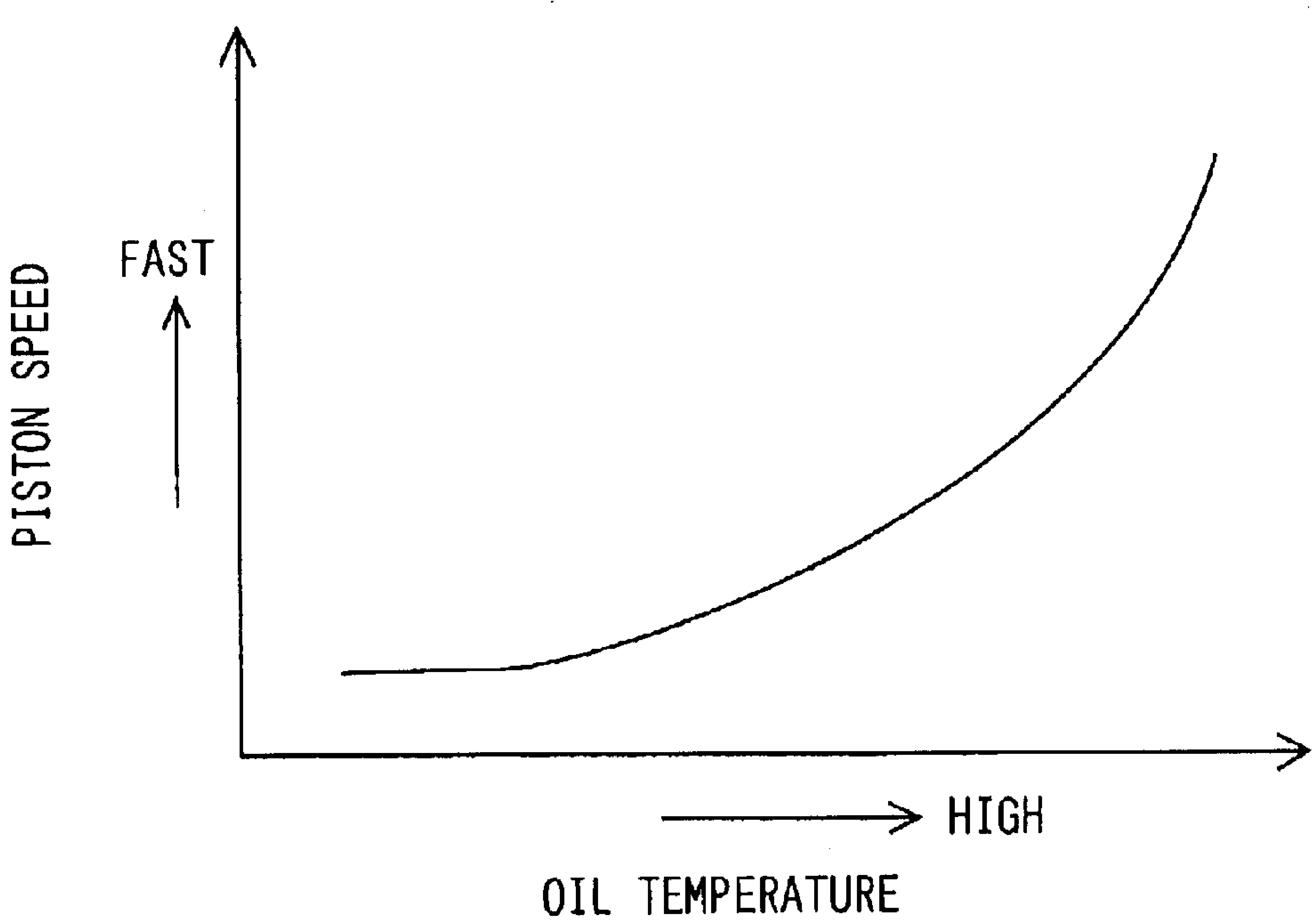

PISTON SPEED
FAST
HIGH
OIL TEMPERATURE

FIG. 7

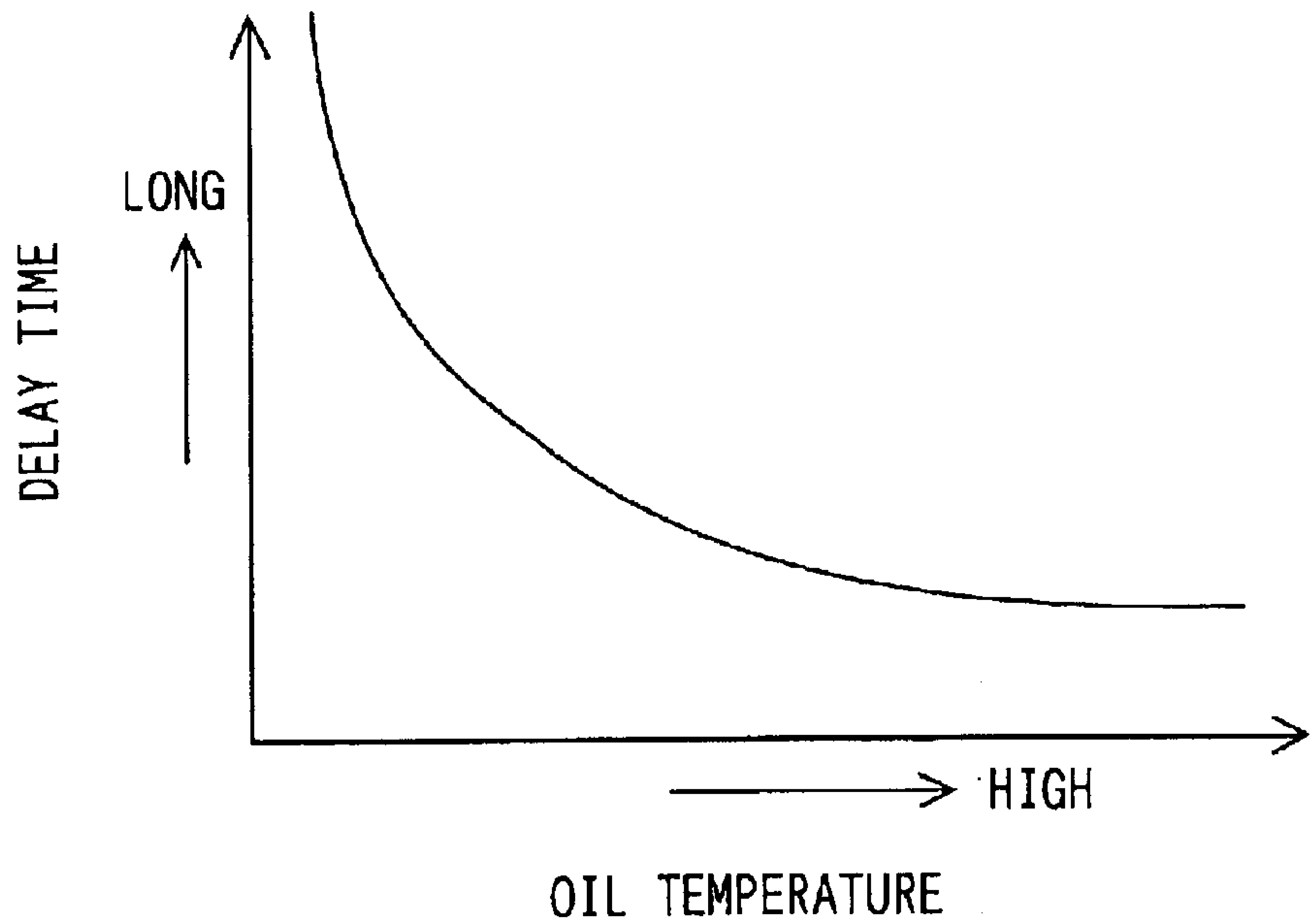

LONG
DELAY TIME
HIGH
OIL TEMPERATURE

FIG. 8

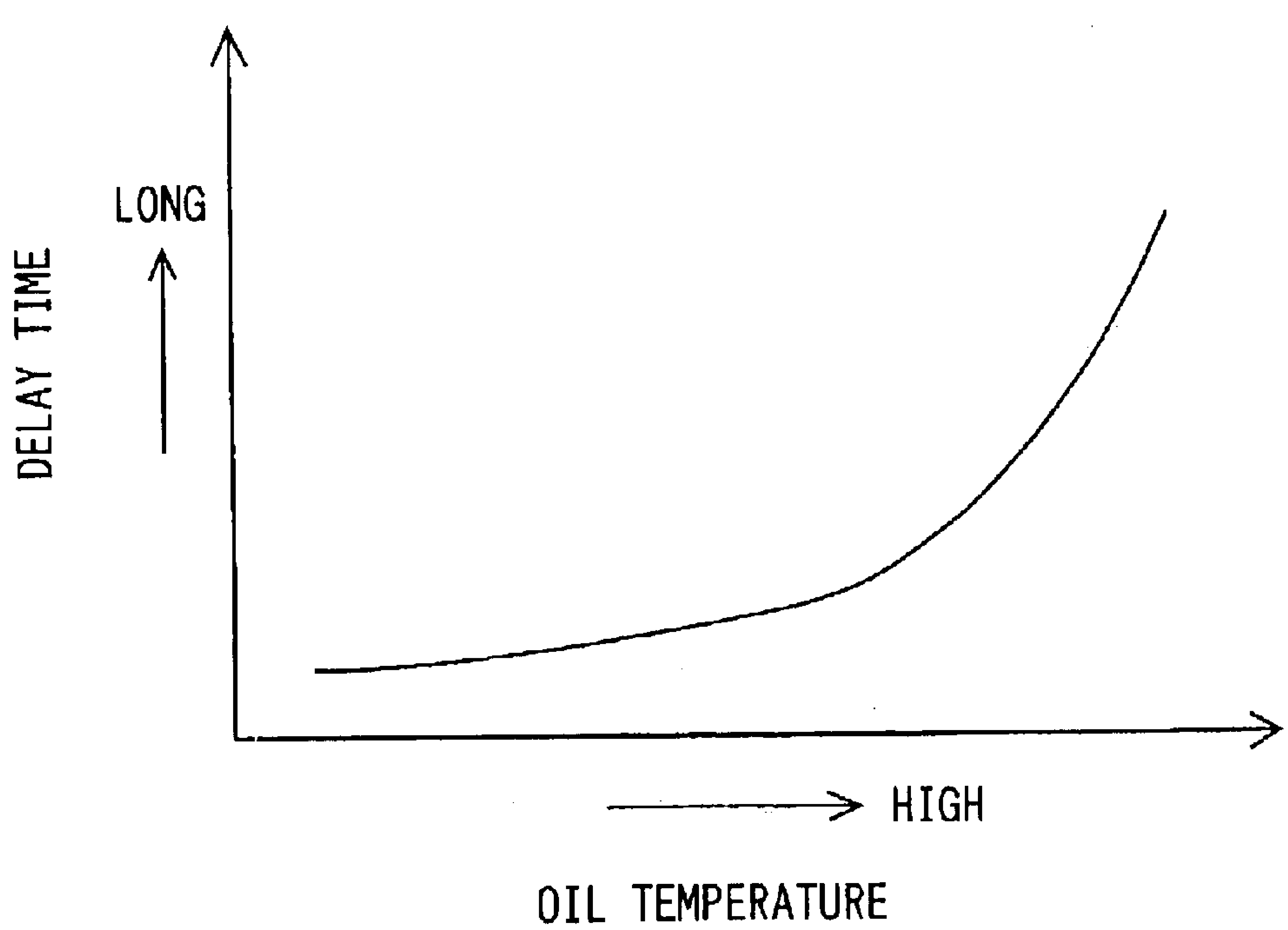

LONG
DELAY TIME
HIGH
OIL TEMPERATURE

FIG. 9A

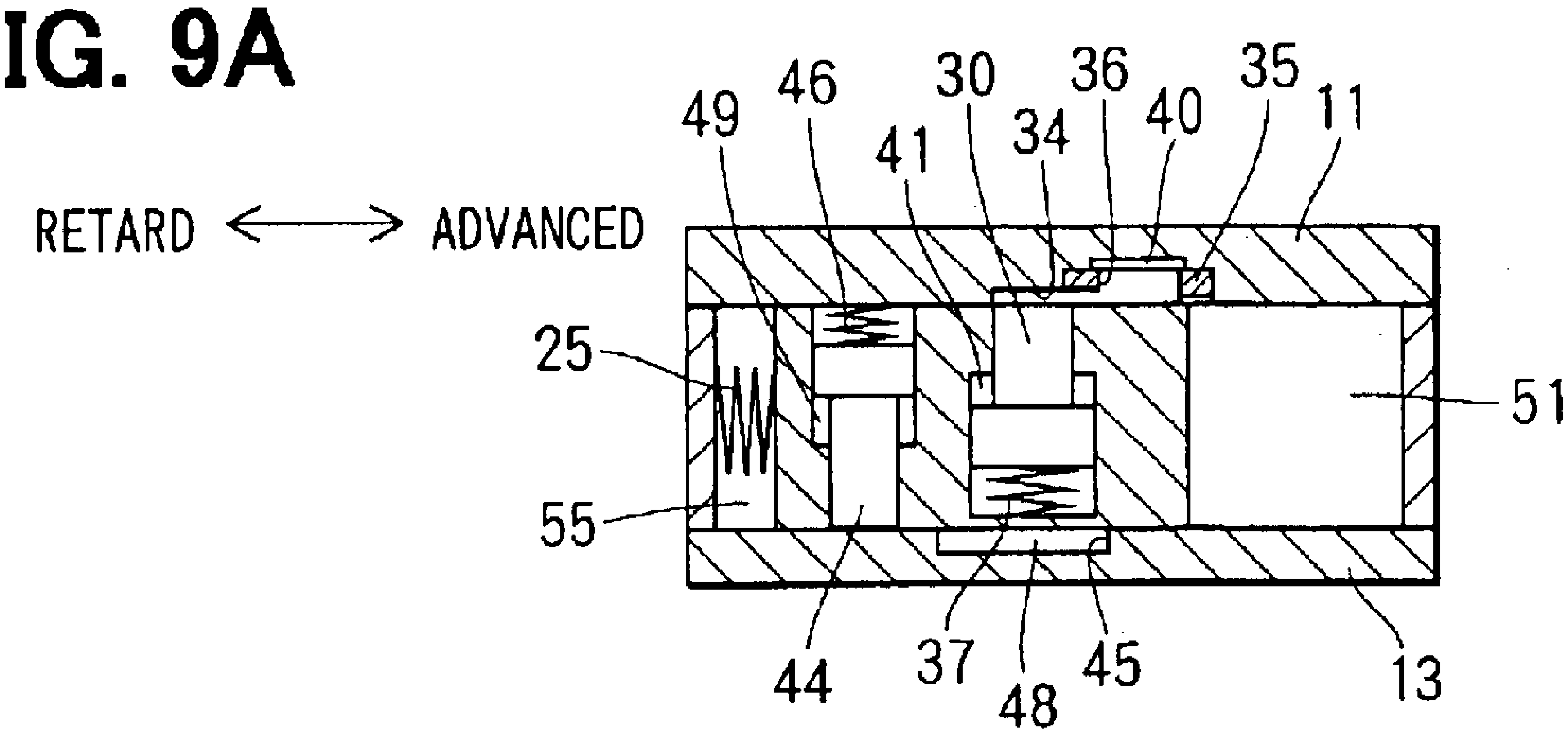


FIG. 9B

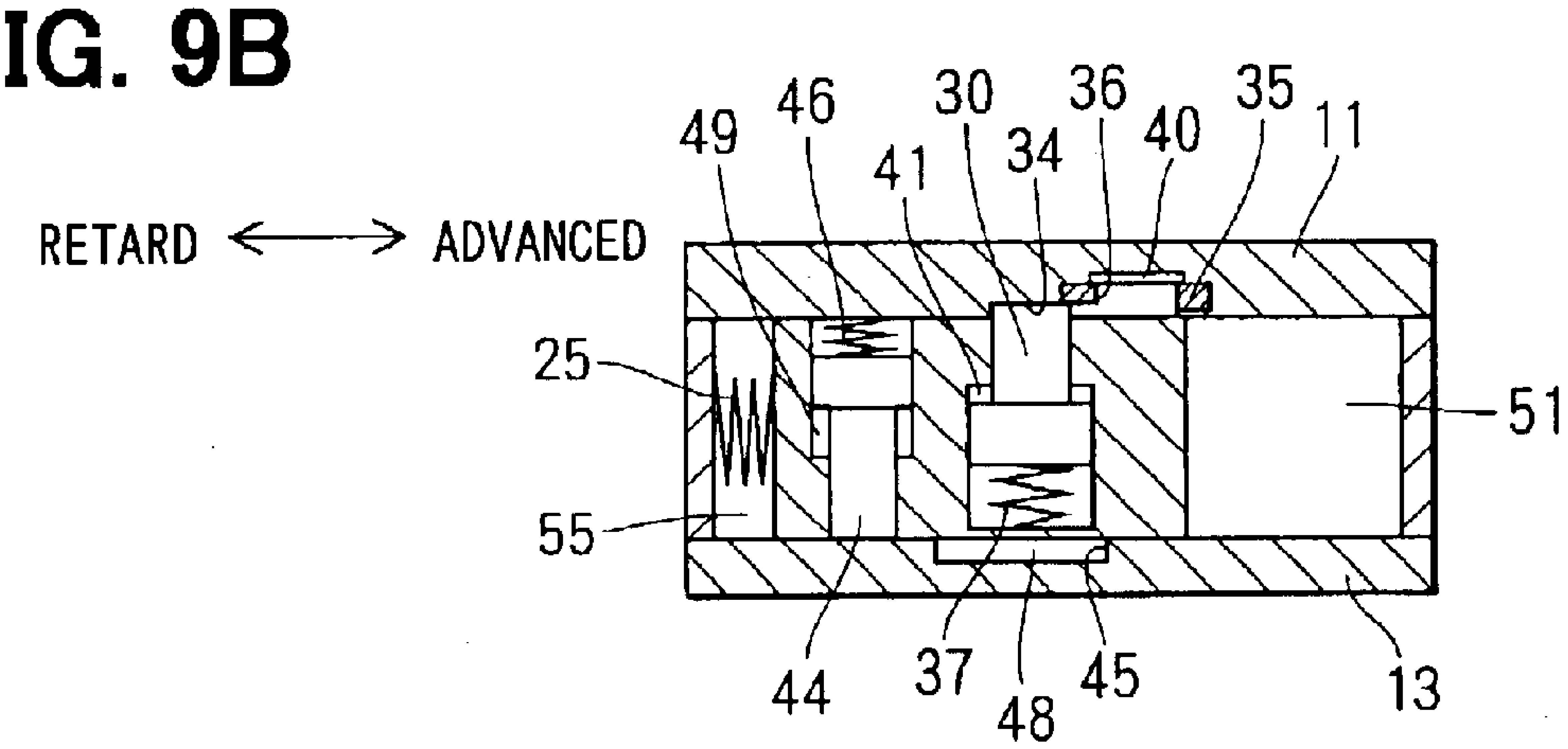


FIG. 9C

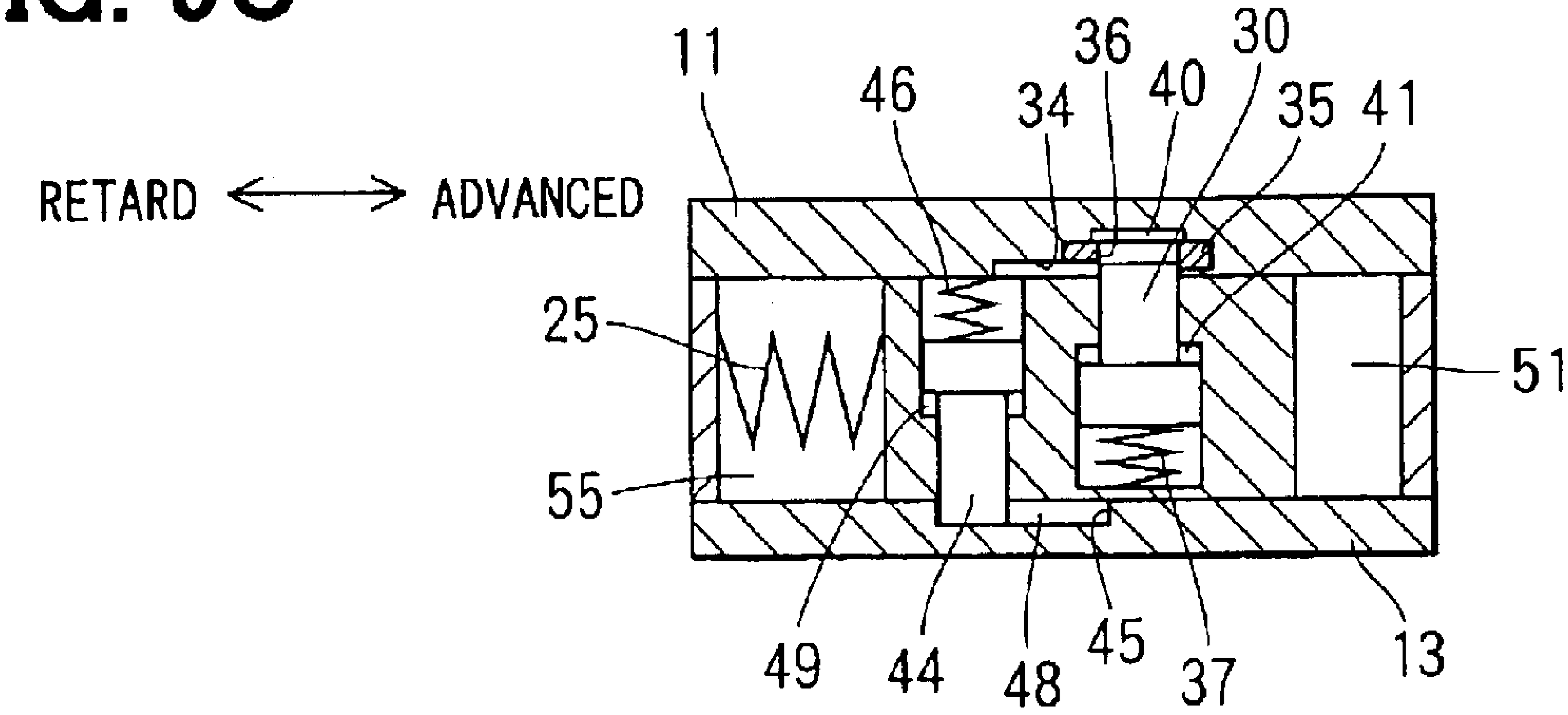
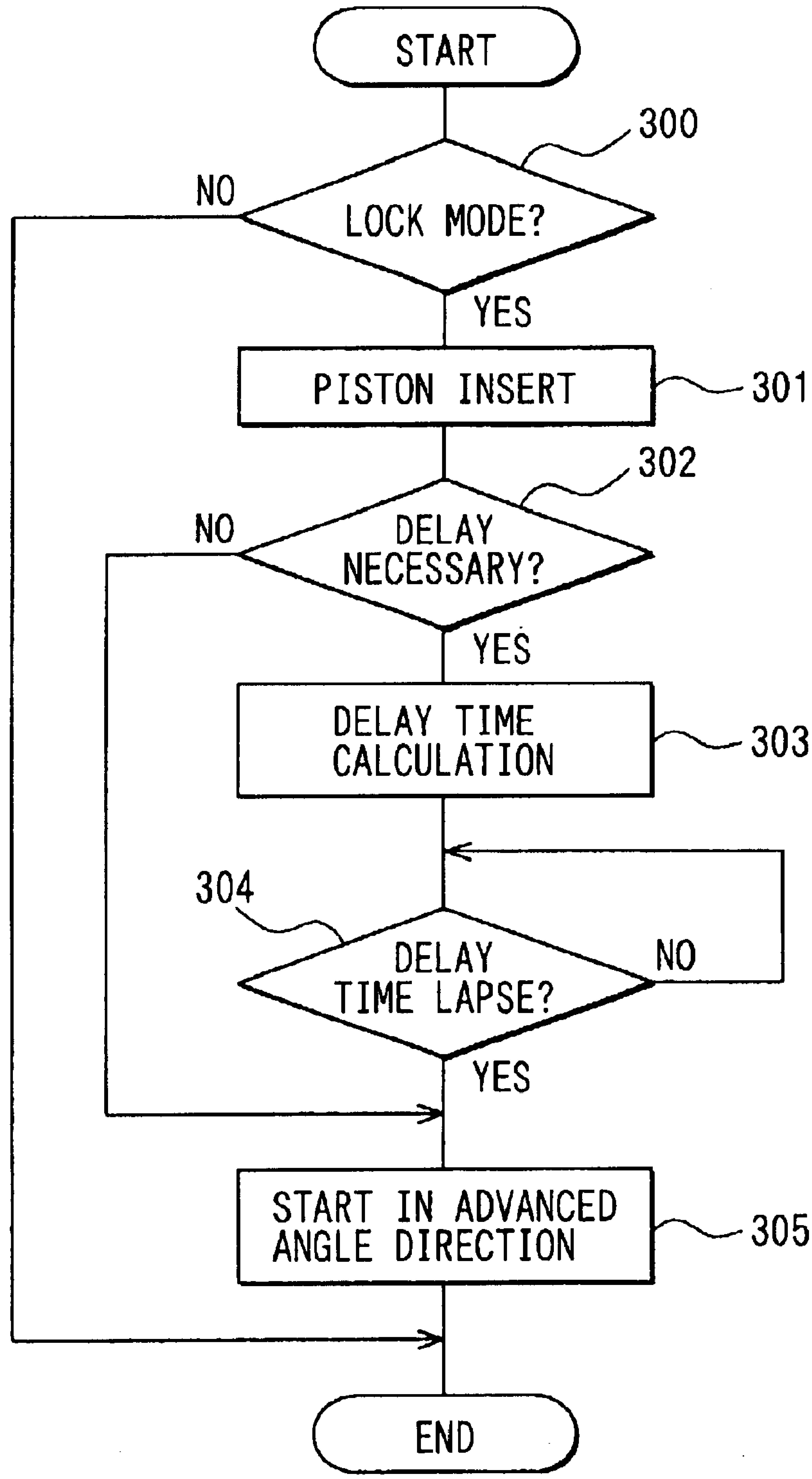


FIG. 10



START
300
LOCK MODE?
NO
YES
PISTON INSERT
301
302
DELAY NECESSARY?
NO
YES
DELAY TIME CALCULATION
303
304
DELAY TIME LAPSE?
NO
YES
START IN ADVANCED ANGLE DIRECTION
305
END

FIG. 11A

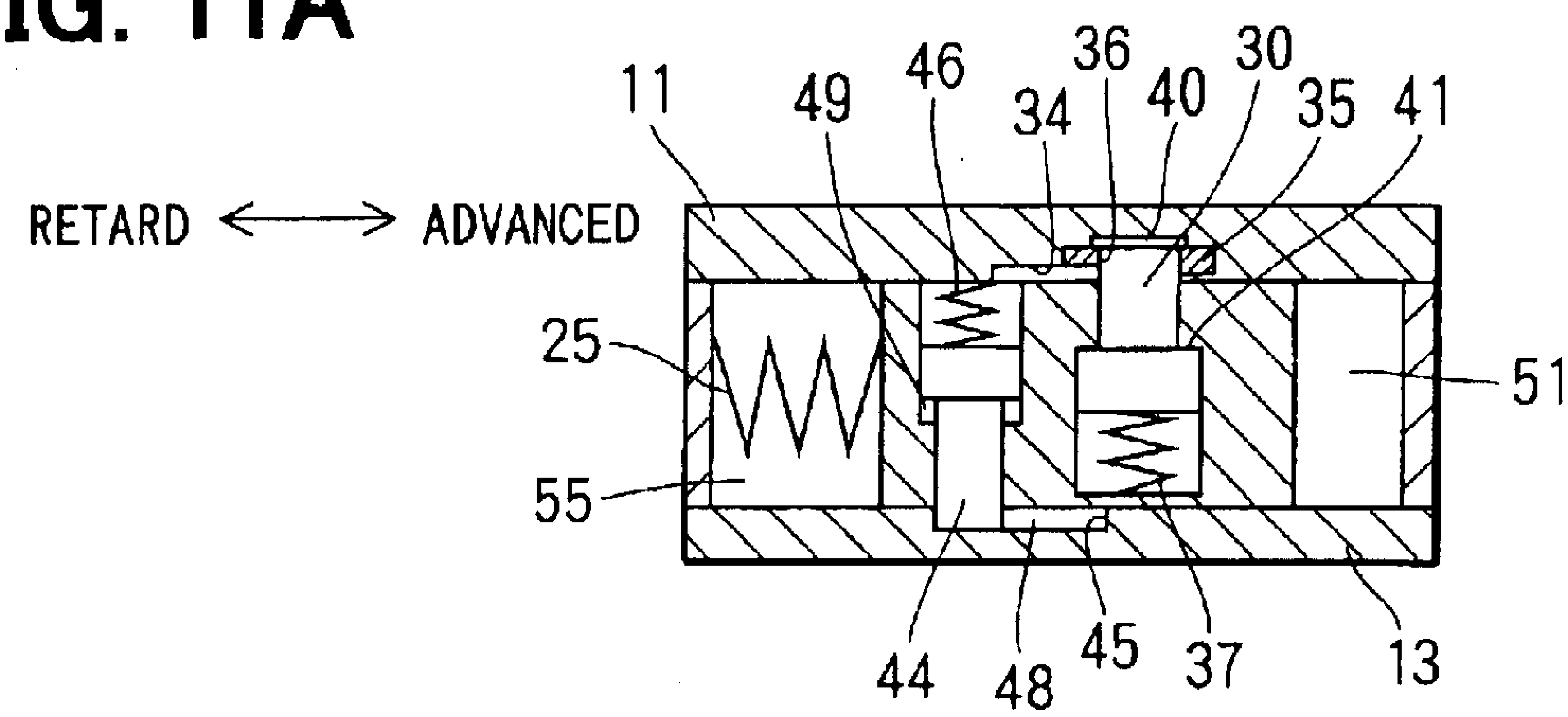


FIG. 11B

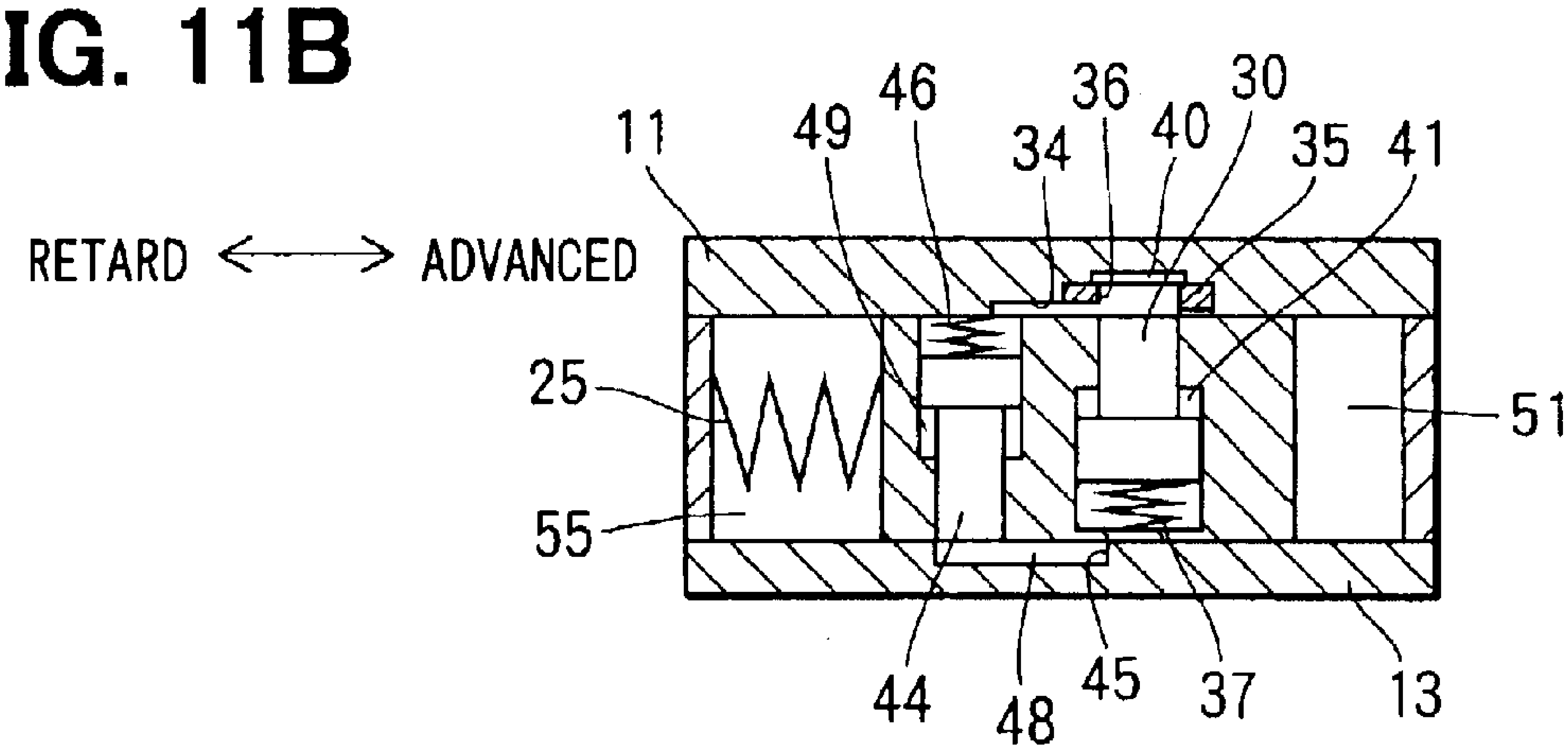


FIG. 11C

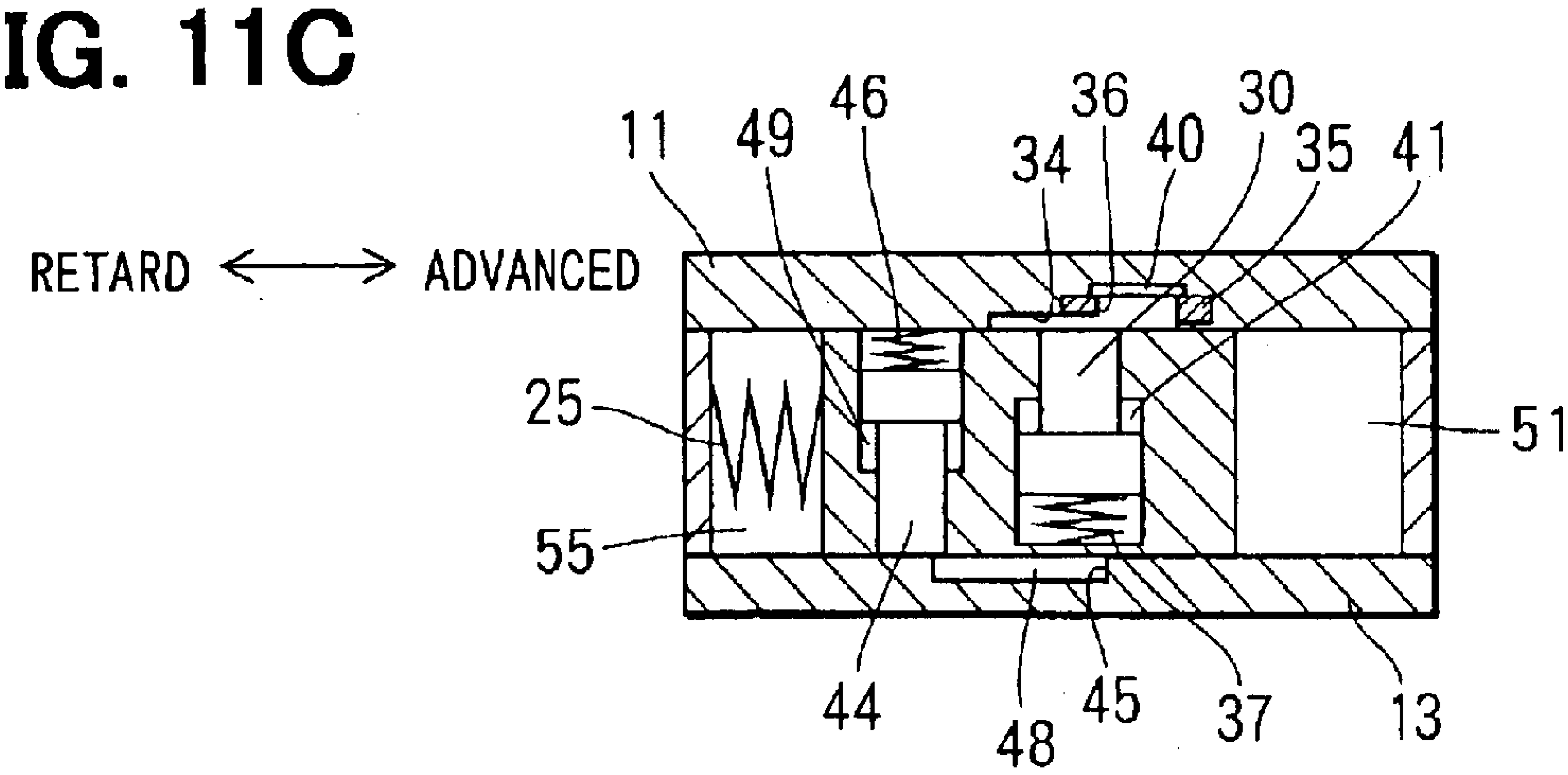


FIG. 12

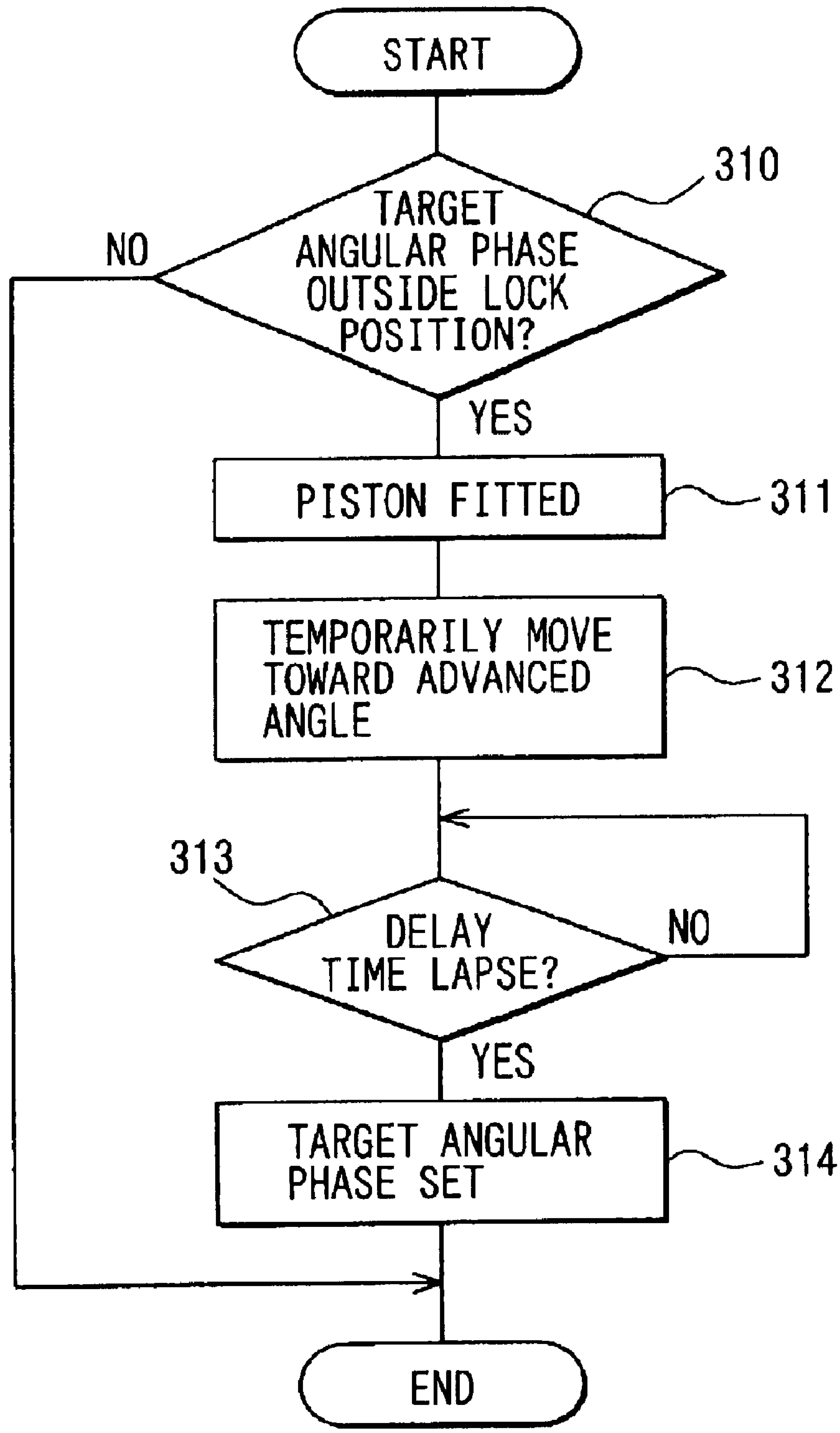

START
TARGET ANGULAR PHASE OUTSIDE LOCK POSITION?
310
NO
YES
PISTON FITTED
311
TEMPORARILY MOVE TOWARD ADVANCED ANGLE
312
313
DELAY TIME LAPSE?
NO
YES
TARGET ANGULAR PHASE SET
314
END

FIG. 13A

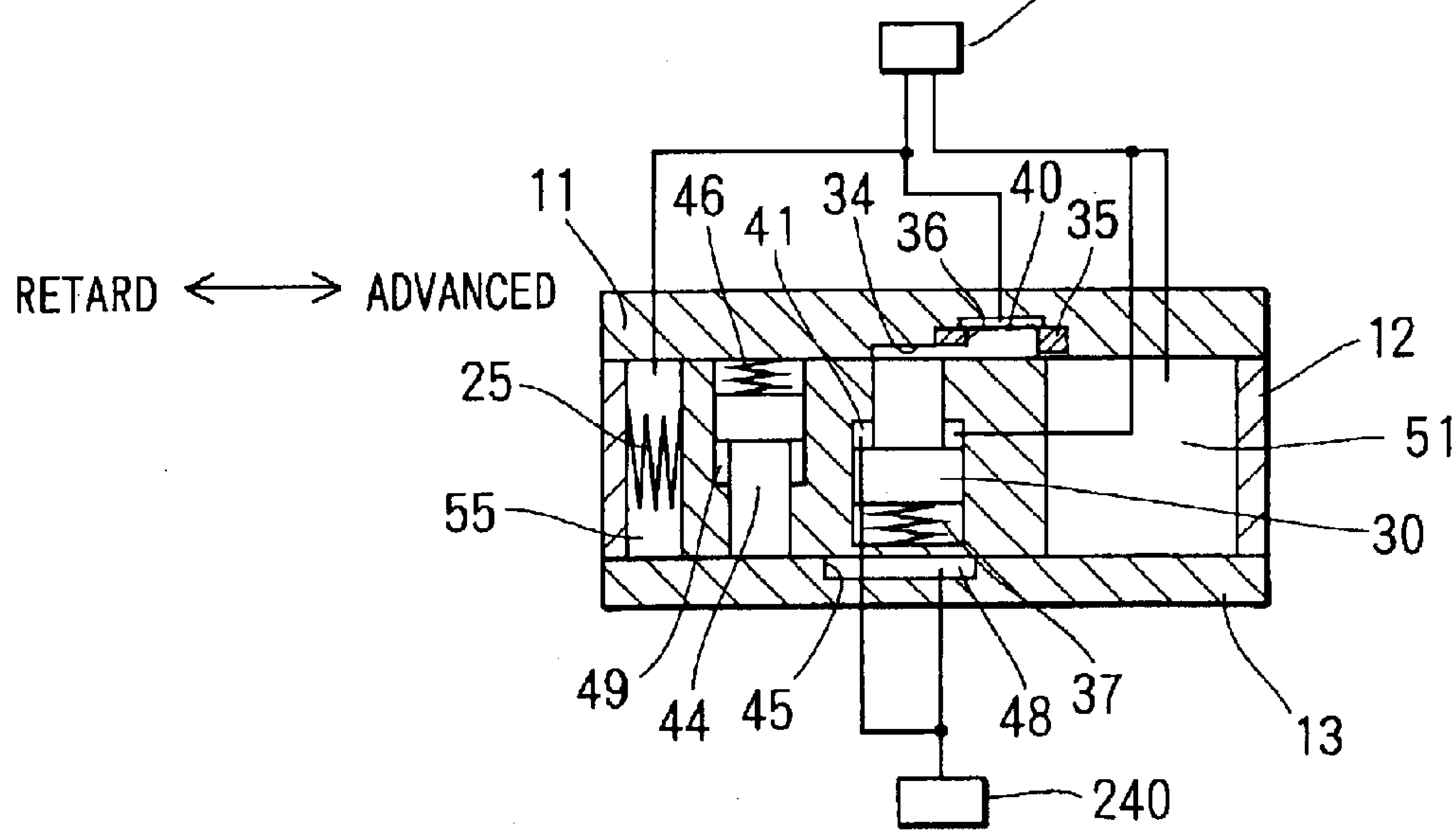


FIG. 13B

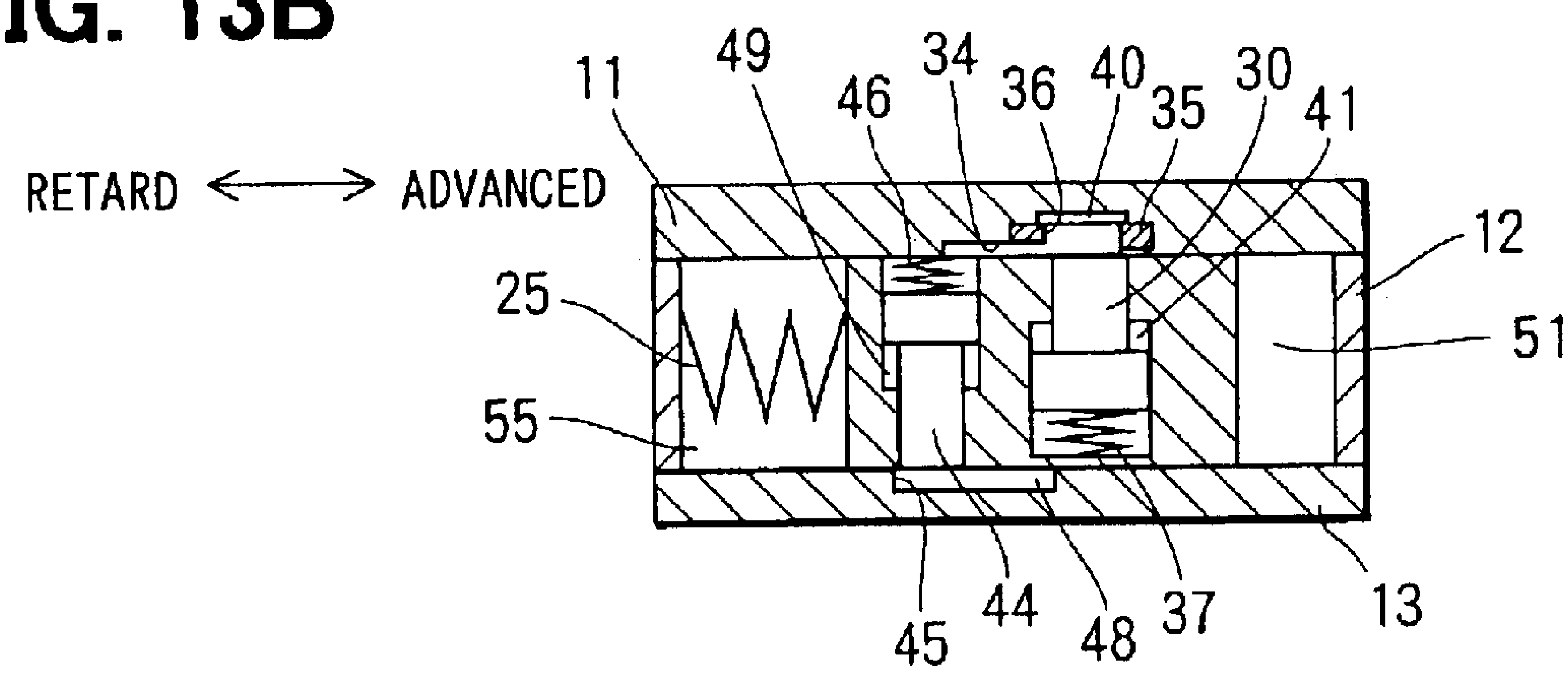


FIG. 13C

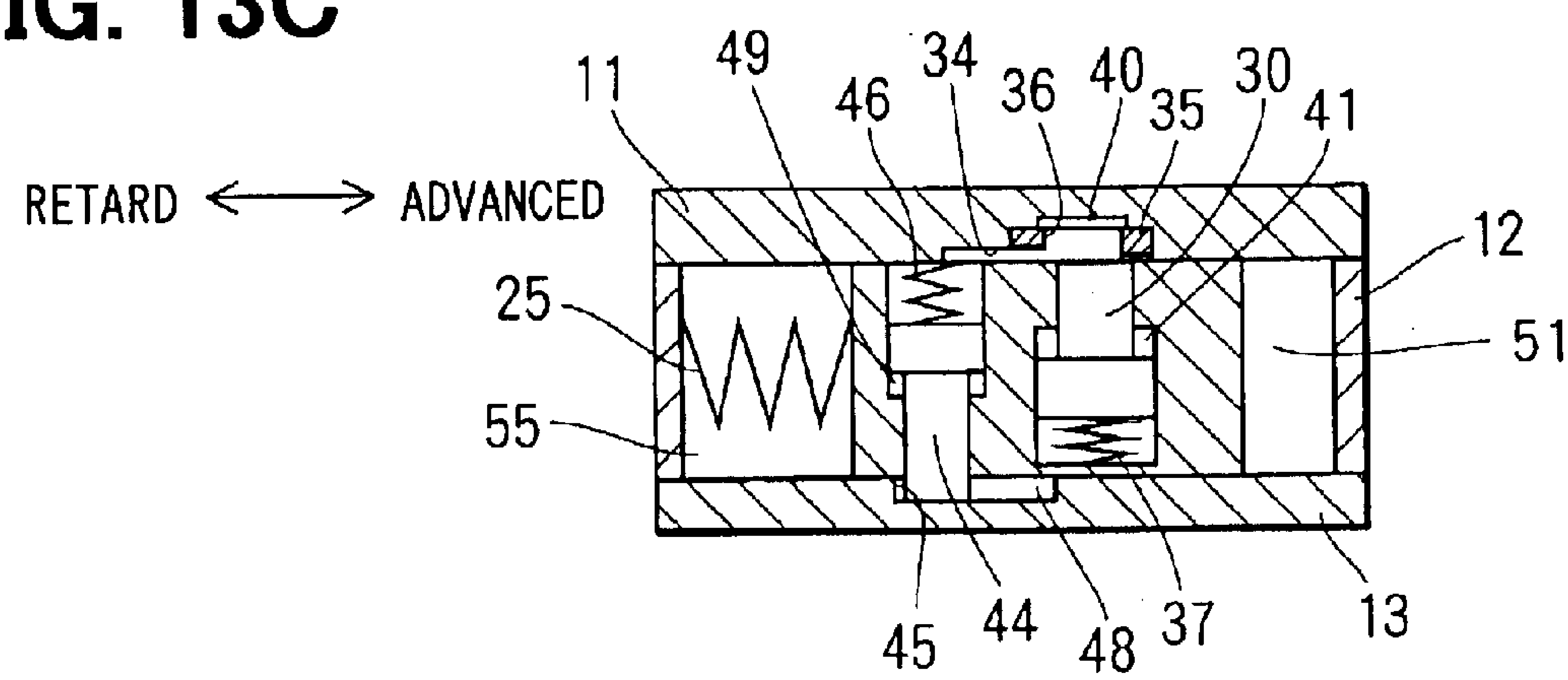


FIG. 14

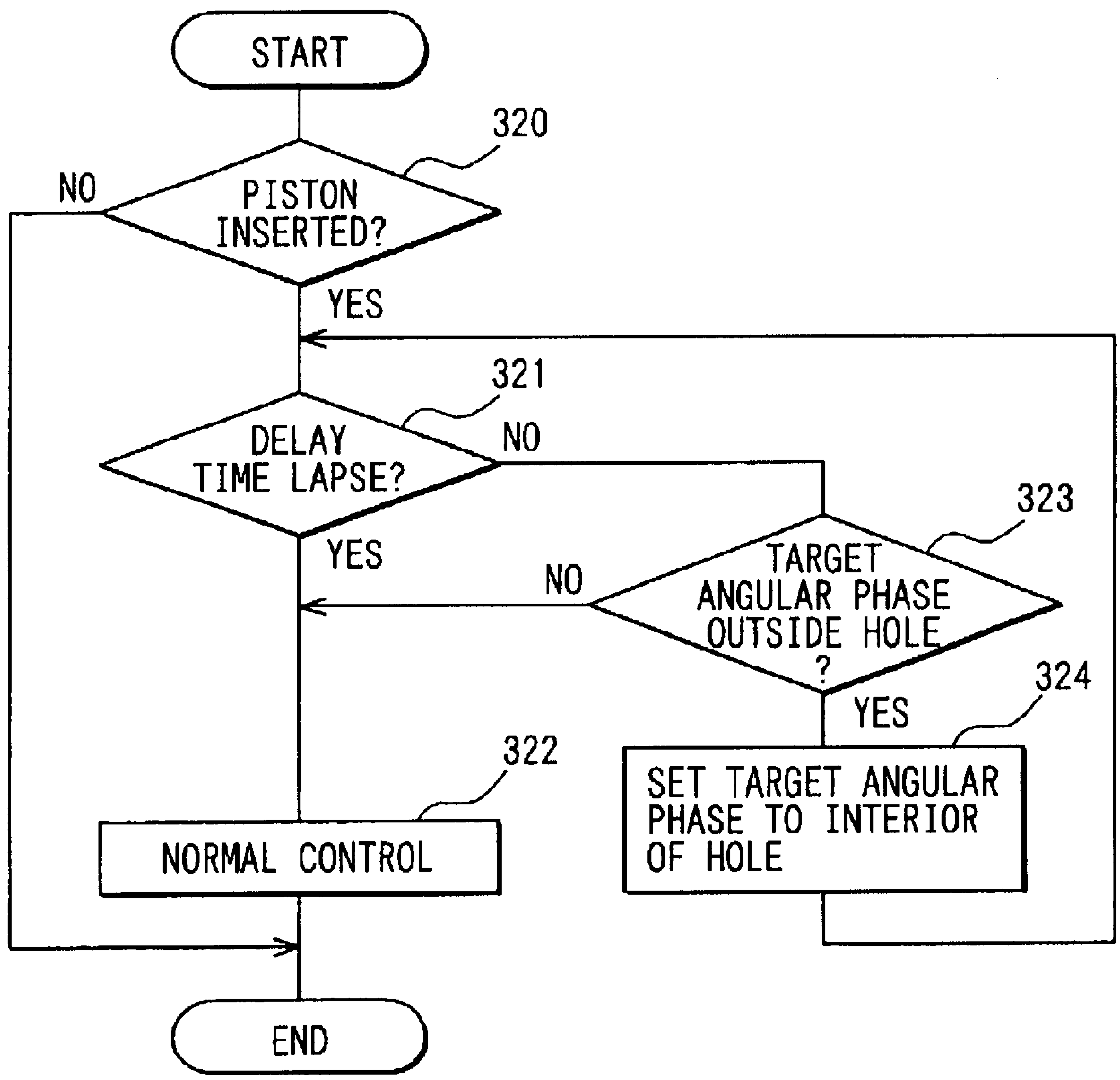

START
320
PISTON INSERTED?
NO
YES
321
DELAY TIME LAPSE?
NO
YES
323
TARGET ANGULAR PHASE OUTSIDE HOLE ?
NO
YES
324
SET TARGET ANGULAR PHASE TO INTERIOR OF HOLE
322
NORMAL CONTROL
END

FIG. 15A

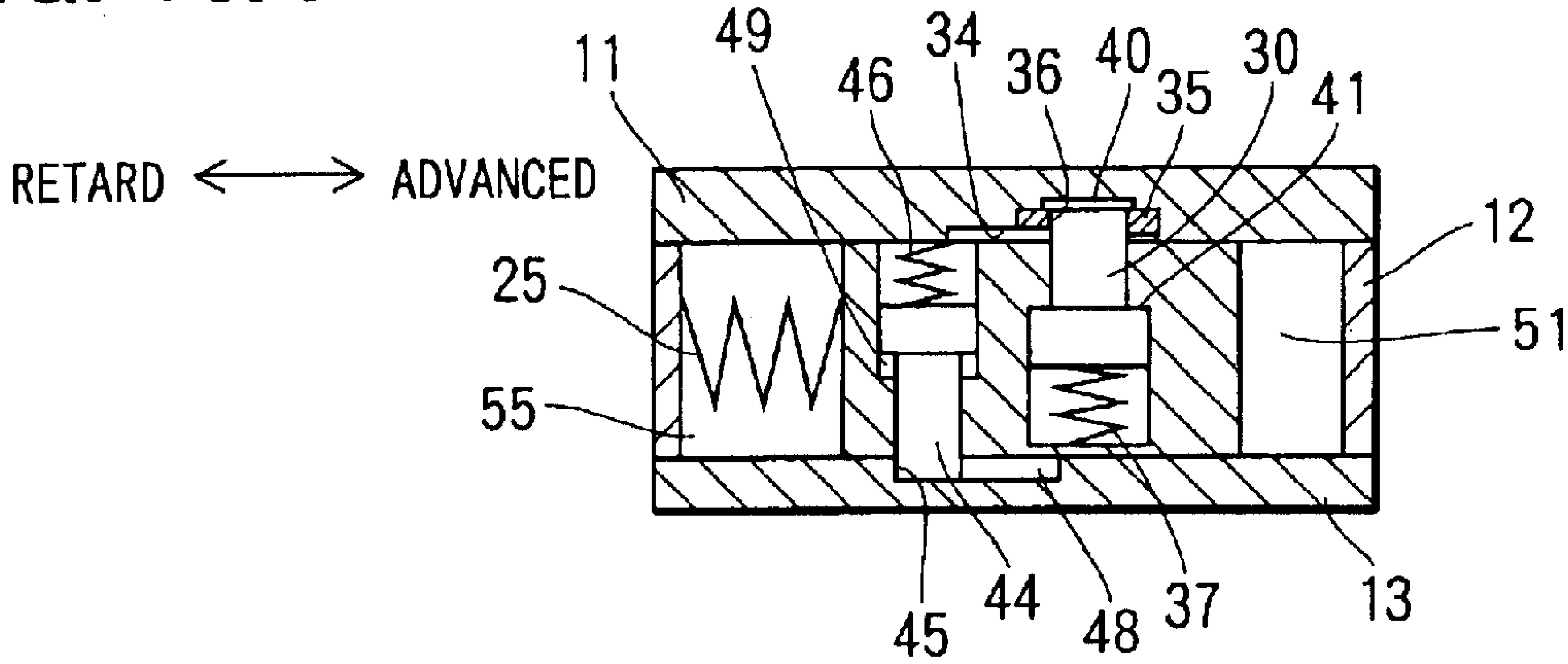


FIG. 15B

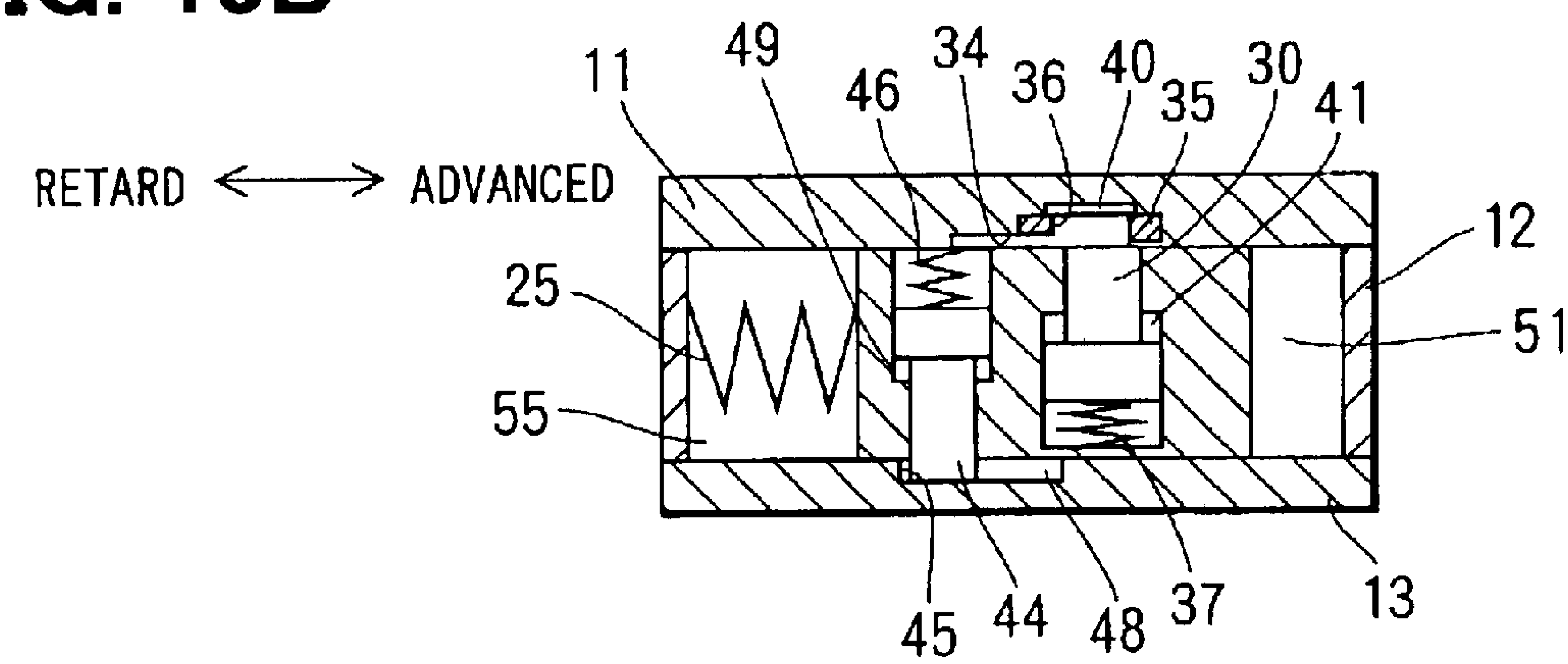


FIG. 15C

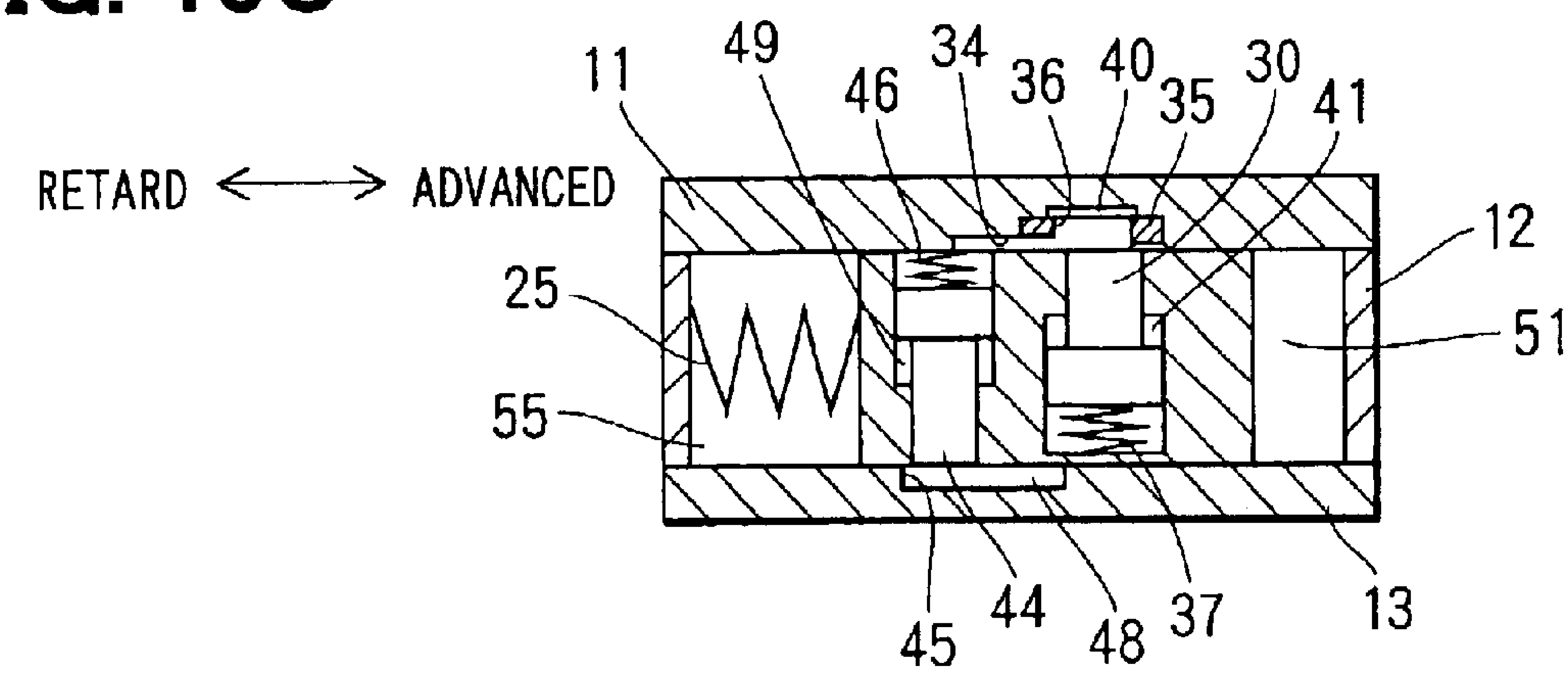
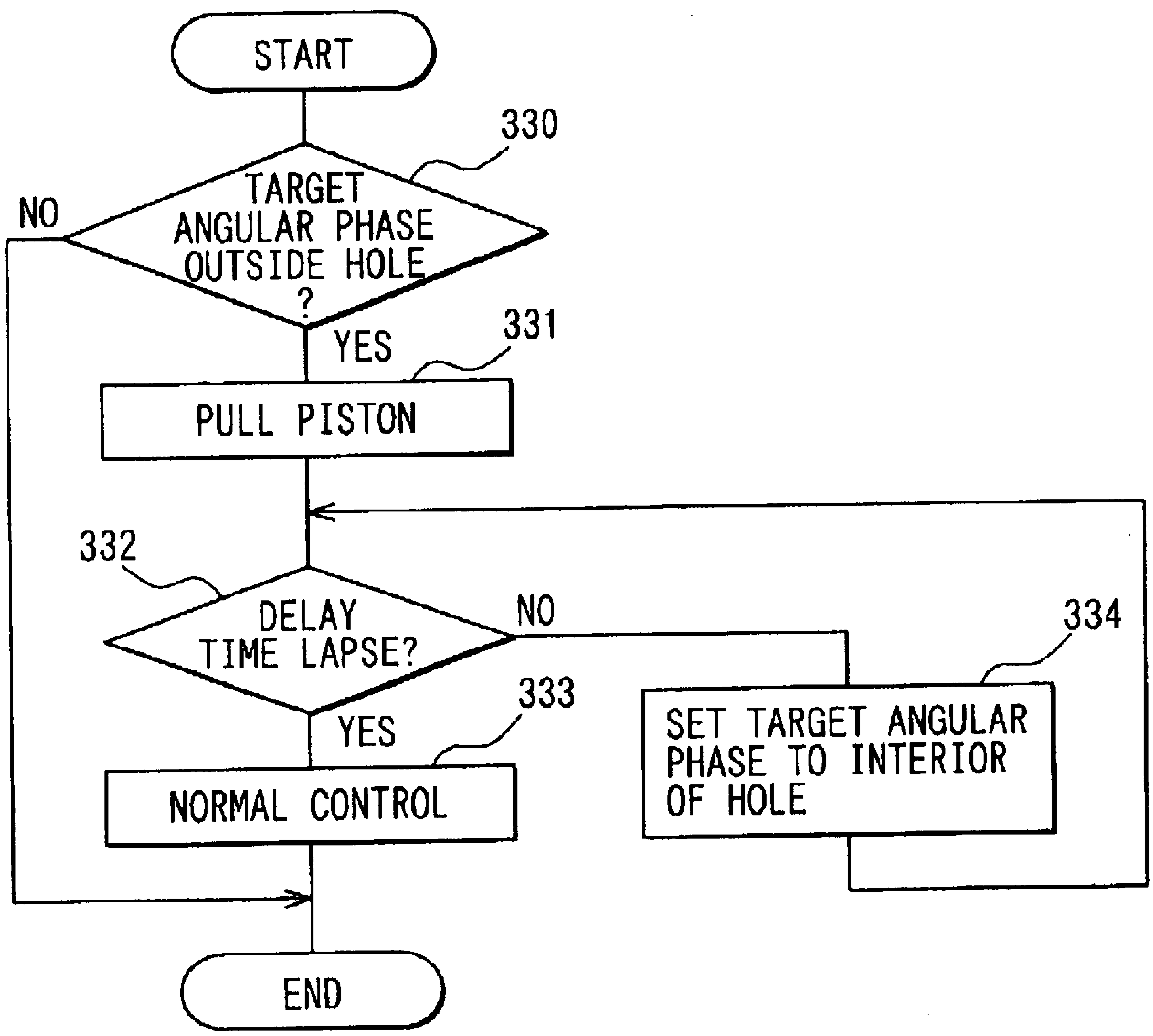


FIG. 16


START
330
TARGET ANGULAR PHASE OUTSIDE HOLE ?
NO
YES
331
PULL PISTON
332
DELAY TIME LAPSE?
NO
YES
333
NORMAL CONTROL
334
SET TARGET ANGULAR PHASE TO INTERIOR OF HOLE
END

VALVE TIMING ADJUSTING APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority of Japanese Patent Application No. 2002-88300 filed on Mar. 27, 2002, the content of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a valve timing adjusting apparatus that adjusts valve opening and closing timing (a valve timing) of at least one of an intake valve and an exhaust valve of an internal combustion engine (engine) and a method of controlling the same.

2. Description of Related Art

There is known a valve timing adjusting apparatus in which valve timing of at least one of an intake valve and an exhaust valve is adjusted by hydraulically controlling angular phase of a driven side rotating member rotatable together with a camshaft relative to a drive side rotating member receiving drive force from a crankshaft of an engine and rotatable together with the crankshaft, that is, controlling angular phase of the camshaft relative to the crankshaft to a given value.

According to a conventional vane type valve timing adjusting apparatus, a vane as the driven side rotating member is accommodated in the drive side rotating member in such a manner that angular phase of the vane relative to the drive side rotating member is variable and defined by controlling hydraulic pressure applied to the vane. Further, according to another conventional valve timing adjusting apparatus, a drive force transmitting member disposed between the drive side rotating member and the driven side rotating member is provided with a helical spline engagement mechanism and angular phase of the driven side rotating member relative to the drive side rotating member is varied by hydraulically moving reciprocatingly the drive force transmitting member.

In the valve timing adjusting apparatus mentioned above, it is preferable for a purpose of preventing engine cranking failure when the engine is cranked that the valve timing of at least one of the intake valve and the exhaust valve is kept at a middle between the most retard timing and the most advanced timing that is the most adequate timing for securing efficient engine cranking.

For example, in the valve timing adjusting apparatus in which a piston is provided in the driven side rotating member and a fitting hole, in which the piston can be fitted, is provided in the drive side rotating member, the angular phase of the driven side rotating member relative to the drive side rotating member is locked to the middle position between the most retard angular position and the most advanced angular position by inserting the piston into the fitting hole when the engine stops. Operation of fitting the piston in the fitting hole or operation of pulling the piston out of the fitting hole is controlled by force balance between biasing force of a spring urging the piston toward the fitting hole and hydraulic pressure acting on the piston in a direction in which the piston is pulled out of the fitting hole.

Further, in a certain engine condition, for example, in a case of rapidly reducing vehicle speed during a period when the vehicle is running at high and constant speed, it is

preferable for preventing abnormal engine operation that the valve timing is held within a limited range between the most retard timing and the most advanced timing by controlling the angular phase of the driven side rotating member relative to the driven side rotating member to keep within an angular range corresponding to the limited range.

For example, in the valve timing adjusting apparatus in which the drive side rotating member is provided with an arc shaped restriction hole extending in a direction in which the driven side rotating member rotates relatively to the drive side rotating member and the driven side rotating member is provided with a piston that can be inserted into the restriction hole, the angular phase of the driven side rotating member relative to the drive side rotating member is controlled within an angular range defined with opposite ends of the arc shaped restriction hole by inserting the piston into the restriction hole.

However, rotating speed of the driven side rotating member relative to the drive side rotating member, speed of inserting the piston into the fitting hole and speed of pulling the piston out of the restriction hole are variable according to changes of pressure, temperature and the like of operating oil supplied from a hydraulic pressure supply source. Accordingly, in a structure in which the angular phase of the driven side rotating member relative to the drive side rotating member is locked to the middle angular position when the piston is inserted into the fitting, hole or in a structure in which the angular phase of the driven side rotating member relative to the drive side rotating member is restricted within the angular range defined by opposite ends of the arc shaped restriction hole when the piston is inserted into the restriction hole, it sometimes happens that the piston passes the fitting or restriction hole before the piston is inserted into the hole or the piston is unlikely pulled out of the hole since the drive side rotating member excessively rotates relatively to the drive side rotating member before the piston has been pulled out of the hole.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a valve timing adjusting apparatus in which a lock piston can be fitted in or pulled out of a fitting hole without fail.

Another object of the present invention is to provide a valve timing adjusting apparatus in which a restriction piston can be inserted into or pulled out of a restriction hole without fail.

A further object of the present invention is to provide a method of controlling the valve timing adjusting apparatus.

To achieve the above object, a valve timing adjusting apparatus disposed between a drive shaft of an internal combustion engine and a driven shaft causing an opening and closing operation of at least one of an intake valve and an exhaust valve and operative to change an angular phase of the driven shaft relative to the drive shaft so that opening and closing timing of the at least one of an intake valve and an exhaust valve may be varied has drive and driven side rotating members, rotation control pressure chamber, a lock piston, a fitting hole and an angular phase locking pressure chamber.

The drive side rotating member is rotated together with the drive shaft. The driven side rotating member is rotated together with the driven shaft. The rotation control pressure chamber is operative to rotate the driven side rotating member relative to the drive side rotating member so that angular phase of the driven side rotating member relative to the drive side rotating member is controlled to a target position between the most retard angle position and the most advanced angle position in response to hydraulic pressure applied thereto. The lock piston is provided in one of the driven and drive side rotating members. The fitting hole is provided in the other of the driven and drive side rotating members. The angular phase locking pressure chamber is operative to execute one of first and second operations when hydraulic pressure is applied thereto and the other of the first and second operations when application of the hydraulic pressure thereto is released. The first operation is to insert the lock piston into the fitting hole so as to lock the angular phase of the driven side rotating member relative to the drive side rotating member to a middle position between the most retard angle position and the most advanced angle position, and the second operation is to pull the lock piston out of the fitting hole so as to release lock of the angular phase of the driven side rotating member relative to the drive side rotating member at the middle position.

With the valve timing adjusting apparatus mentioned above, a supply route of the hydraulic pressure to the rotation control pressure chamber is different from that to the angular phase locking pressure chamber and, when at least one of the first and second operations is executed, start timing of rotation of the driven side rotating member relative to the drive side rotating member so as to change the angular phase of the driven side rotating member relative to the drive side rotating member to the target position is retard by a given delay time from start timing of execution of the at least one of the first and second operations.

It is preferable that the lock piston is provided at an axial end thereof with a tapered portion whose diameter is smaller toward the round hole, the fitting hole is provided at an opening end thereof with a chamfering portion whose diameter is larger toward the piston, and, when the first operation is executed, the given delay time by which the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard from the start timing of execution of the first operation is larger than time required for the tapered portion to pass the chamfering portion after the first operation starts.

When the intake or exhaust valve is driven, the driven shaft receives fluctuating torque acting in retard or advanced angle direction. Since average of the fluctuating torque acts in a retard angle direction, the driven side rotating member receives the fluctuating torque which causes the angular phase of the driven side rotating member relative to the drive side rotating member to change in retard angle direction.

Accordingly, it is preferable that, after the second operation starts, the hydraulic pressure is applied to the rotation control pressure chamber in such a manner that the angular phase of the driven side rotating member relative to the drive side rotating member is kept at the middle position between the most retard angle position and the most advanced angle position or temporarily moved to a position slightly shifted from the middle position toward the advanced angle position before the given delay time lapses. Since the fluctuating torque acting on the driven side rotating member in retard angle direction is reduced, the lock piston can be pulled out of the fitting hole with less frictional resistance.

A rotation speed of the driven side rotating member relative to the drive side rotating member and a moving speed of the lock piston are variable according to change of pressure of the operation oil. Further, the rotation speed of the driven side rotating member relative to the drive side rotating member and the moving speed of the lock piston are also variable according to change of viscosity of the operation oil that is changed by temperature of the operation oil.

Accordingly, it is preferable that the given delay time by which the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard from the start timing of execution of the at least one of the first and second operations is determined by sensor signals representing pressure and temperature of fluid applied to at least one of the rotation control pressure chamber and the angular phase locking pressure chamber.

Preferably, the valve timing adjusting apparatus further has a restriction piston, a restriction hole and an angular phase restriction pressure chamber. The restriction piston is provided in one of the driven and drive side rotating members. The restriction hole is formed in shape of an arc extending within a given angular range and provided in the other of the driven and drive side rotating members. The angular phase restriction pressure chamber is operative to execute one of third and fourth operations when hydraulic pressure is applied thereto and the other of the third and fourth operations when application of the hydraulic pressure thereto is released. The third operation is to insert the restriction piston into the restriction hole so as to restrict rotation of the driven side rotating member relative to the drive side rotating member within the given angular range and the fourth operation is to pull the restriction piston out of the restriction hole so as to release restriction of rotation of the driven side rotating member relative to the drive side rotating member within the given angular range. With the construction mentioned above, a supply route of the hydraulic pressure to the angular phase restriction pressure chamber is same as that to the angular phase locking pressure chamber, an end of the given angular range is at a position corresponding to the middle position between the most retard angle position and the most advanced angle position and the other end of the given angular range is at a position away from the middle position toward the most advanced angle position and, when the third operation is executed together with the first operation, the restriction piston abuts on the end of the given angular range within the restriction hole.

As an alternative, a valve timing adjusting apparatus disposed between a drive shaft of an internal combustion engine and a driven shaft causing an opening and closing operation of at least one of an intake valve and an exhaust valve and operative to change an angular phase of the driven shaft relative to the drive shaft so that opening and closing timing of the at least one of an intake valve and an exhaust valve may be varied has drive and driven side rotating members, rotation control pressure chamber, a restriction piston, a restriction hole and an angular phase restriction pressure chamber.

The drive side rotating member is rotated together with the drive shaft. The driven side rotating member is rotated together with the driven shaft. The rotation control pressure chamber is operative to rotate the driven side rotating member relative to the drive side rotating member so that angular phase of the driven side rotating member relative to the drive side rotating member is controlled to a target position between the most retard angle position and the most advanced angle position in response to hydraulic pressure applied thereto. The restriction piston is provided in one of the driven and drive side rotating members. The restriction hole is provided in the other of the driven and drive side rotating members. The angular phase restriction pressure chamber is operative to execute one of first and second operations when hydraulic pressure is applied thereto and the other of the first and second operations when application of the hydraulic pressure thereto is released. The first operation is to insert the restriction piston into the restriction hole so as to restrict rotation of the driven side rotating member relative to the drive side rotating member within the given angular range and the fourth operation being to pull the restriction piston out of the restriction hole so as to release restriction of rotation of the driven side rotating member relative to the drive side rotating member within the given angular range.

With the valve timing adjusting apparatus mentioned above, a supply route of the hydraulic pressure to the rotation control pressure chamber is different from that to the angular phase restriction pressure chamber and, when at least one of the first and second operations is executed, start timing of rotation of the driven side rotating member relative to the drive side rotating member so as to change the angular phase of the driven side rotating member relative to the drive side rotating member to the target position is retard by a given delay time from start timing of execution of the at least one of the first and second operations.

When the first operation is executed, the hydraulic pressure is applied to the rotation control pressure chamber in such a manner that, if the restriction piston is outside the given angular range of the restriction hole, the angular phase of the driven side rotating member relative to the drive side rotating member is temporarily moved to a position slightly inside the given angular range of the restriction hole before the given delay time lapses, whereby, when the driven side rotating member is rotated relatively to the drive side rotating member after the given delay time lapses, the target position of the angular phase of the driven side rotating member relative to the drive side rotating member is restricted within the given angular range since the restriction piston abuts on the retard angle side end or the advanced angle side end.

Further, it is preferable that, after the second operation starts, the hydraulic pressure is applied to the rotation control pressure chamber in such a manner that, before the given delay time lapses, the angular phase of the driven side rotating member relative to the drive side rotating member is temporarily moved to a position slightly away inward from the retard angle side end or the advanced angle side end of the restriction hole on which the restriction piston abuts so as to pull smoothly the restriction piston out of the restriction hole.

Preferably, the given delay time by which the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard from the start timing of execution of the at least one of the first and second operations is determined by sensor signals representing pressure and temperature of fluid applied to at least one of the rotation control pressure chamber and the angular phase restriction pressure chamber.

The valve timing adjusting apparatus further has a lock piston, a fitting hole and an angular phase locking pressure chamber. The lock piston is provided in one of the driven and drive side rotating members. The fitting hole is provided in the other of the driven and drive side rotating members. The angular phase locking pressure chamber is operative to execute one of third and fourth operations when hydraulic pressure is applied thereto and the other of the third and fourth operations when application of the hydraulic pressure thereto is released. The third operation is to insert the lock piston into the fitting hole so as to lock the angular phase of the driven side rotating member relative to the drive side rotating member to a given position within the given angular range of the restriction hole and the second operation is to pull the lock piston out of the fitting hole so as to release lock of the angular phase of the driven side rotating member relative to the drive side rotating member at the given position.

With the construction mentioned above, a supply route of the hydraulic pressure to the angular phase locking pressure chamber is same as that to the rotation control pressure chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the present invention will be appreciated, as well as methods of operation and the function of the related parts, from a study of the following detailed description, the appended claims, and the drawings, all of which form a part of this application. In the drawings:

FIG. **1** is a cross sectional view of a valve timing adjusting apparatus according to a first embodiment of the present invention;

FIG. **2** is a cross sectional view taken along a line II—II in FIG. **1**;

FIG. **3** is schematic cross sectional views of a lock piston and a fitting hole according to the first embodiment;

FIG. **4** is a schematic view showing oil passages according to the first embodiment;

FIG. **5** is a characteristic graph showing relationship between oil temperature and a response speed;

FIG. **6** is a characteristic graph showing relationship between oil temperature and a moving speed of the lock piston;

FIG. **7** is a characteristic graph showing a relationship between oil temperature and delay time;

FIG. **8** is a characteristic graph showing a relationship between oil pressure and delay time;

FIGS. **9**A, **9**B and **9**C are schematic views showing an operation of the lock piston to be inserted into the fitting hole according to the first embodiment;

FIG. **10** is a flow chart showing a control routine when the lock piston is fitted in the fitting hole according to the first embodiment;

FIGS. **11**A, **11**B and **11**C are schematic views showing an operation of the lock piston to be pulled out of the fitting hole according to the first embodiment;

FIG. **12** is a flow chart showing a control routine when the lock piston is pulled out of the fitting hole according to the first embodiment;

FIGS. **13**A, **13**B and **13**C are schematic views showing oil passages and operation of a restriction piston to be inserted into a restriction hole according to a second embodiment of the present invention;

FIG. **14** is a flow chart showing a control routine when the restriction piston is inserted into the restriction hole according to the second embodiment;

FIGS. **15**A, **15**B and **15**C are schematic views showing an operation of the restriction piston to be pulled out of the restriction hole according to a second embodiment; and

FIG. **16** is a flow chart showing a control routine when the restriction piston is pulled out of the restriction hole according to the second embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention are described with reference to figures.

(First Embodiment)

As shown in FIGS. **1** and **2**, a valve timing adjusting apparatus **1** is a hydraulic control device for adjusting a valve timing of an intake valve. The valve timing adjusting apparatus **1** is composed of a main body **2**, a camshaft **3**, a bearing **4** for the camshaft **3**, a spool valve **230** as a first electrically controlled valve and a solenoid valve **240** as a second electrically controlled valve.

As shown in FIG. **1**, drive force of a crankshaft (not shown) constituting a drive shaft is transmitted through the main body **2** to the camshaft **3** constituting a driven shaft. A cam formed in the camshaft **3** drives the intake valve. The main body **2** has a housing **10**, vane rotor **15**, a lock piston **30** and a restriction piston **44** (refer to FIG. **4**). The housing **10** is a drive side rotating member and has a timing gear **11** constituting a side wall, a circumferential wall **12** and a front plate **13** constituting the other side wall. The timing gear **11** and the front plate **13** are in contact with opposite axial ends of the circumferential wall **12**, respectively. The timing gear **11**, the circumferential wall **12** and the front plate **13** are concentrically fixed to one another by bolts. The timing gear **11** is connected via gears (no shown) to the crankshaft for receiving drive force therefrom and rotating together with the crankshaft.

The camshaft **3** is held by the bearing **4**. The drive force of the crankshaft is transmitted via the housing **10** and the vane rotor **15** to the camshaft **3** for an opening and closing operation of the intake valve (not shown). The camshaft **3** is rotatable with the timing gear **11** with a given angular phase difference therebetween. The housing **10** and the camshaft **3** rotate clockwise when viewed in a direction of an arrow A in FIG. **1**. This clockwise direction is advanced angle direction.

As shown in FIG. **2**, the circumferential wall **12** is provided at an inner circumference thereof with four shoes **12***a*, **12***b*, **12***c* and **12***d*, that is, partitions formed in trapezoidal shape, arranged circumferentially at generally regular intervals. Each of inner circumferential surfaces of the shoes **12***a*, **12***b*, **12***c* and **12***d* is formed in arc cross sectional shape. Four fan shaped accommodation chambers **50** are formed in circumferential spaces between adjacent two of the shoes **12***a*, **12***b*, **12***c* and **12***d*. Vanes **15***a*, **15***b*, **15***c* and **15***d* are accommodated in the accommodation chambers **50**, respectively, and movable circumferentially within a given angular range.

The vane rotor **15** has a boss **15***e* and the vanes **15***a*, **15***b*, **15***c* and **15***d* that are arranged around the boss **15***e* circumferentially at generally regular intervals. The vanes **15***a*, **15***b*, **15***c* and **15***d* are rotatably accommodated in the accommodation chambers **50**. Each of the accommodation chambers **50** is partitioned by each of the vanes into two rooms. One is a retard angle hydraulic chamber and the other one is an advanced angle hydraulic chamber. Arrows in FIG. **2** represent retard and advanced angle directions when the vane rotor **15** rotates relatively to the housing **10**. The vane rotor **15** representing the driven side rotating member is in contact with an axial end of the camshaft **3** and fixed to the camshaft **3** by a bolt **21**.

A spring **25** is inserted between the front plate **13** and the vane rotor **15**. An end of the spring **25** is retained by the front plate **13** and the other end thereof is retained by the vane rotor **15**. The spring **25** urges the vane rotor **15** in the advanced angle direction relative to the front plate **13**.

The vane rotor **15** is rotatable relatively to the housing **10**. Inner surfaces of the housing **10** at opposite axial ends, that is, inner walls of the timing gear **11** and the front plate **13**, are in slidable contact with outer surfaces of the vane rotor **15** at the opposite axial ends, respectively. Inner circumference of the circumferential wall **12** is in slidable contact with an outer circumference of the vane rotor **15**.

As shown in FIG. **1**, the lock piston **30** constituting a cylindrical locking member is accommodated to move axially and reciprocatingly in an accommodation hole **38** formed in the vane **15***a*. The timing gear **11** is provided with an arc shaped elongated hole **34** (refer to FIGS. **3** and **4**) whose depth is deeper at an advanced angle end. A fitting ring **35** is press fitted to the elongated hole **34** at the advanced angle end and constitutes a fitting hole **36**. The lock piston **30** can be inserted into and fitted in the fitting hole **36**. The lock piston **30** is provided at an axial end thereof with a tapered portion **31** whose diameter is smaller toward the fitting hole **36**. The fitting hole **36** is provided at an opening end thereof with a chamfering portion **32** whose diameter is larger toward the lock piston **30** so that the lock piston **30** is smoothly inserted into the fitting hole **36**. When the lock piston **30** enters toward the fitting hole **36** by more than length L1 from an entrance of the fitting hole, as shown in FIG. **3**, the lock piston **30** is fitted in the fitting hole **36**. When the lock piston **30** enters toward the fitting hole **36** or the elongated hole **34** by more than length L2 corresponding to a longer one of axial length of the tapered portion **31** and axial length of the chamfering portion **36**, as shown in FIG. **3**, the lock piston **30** does not pass the fitting hole **36** or the elongated hole **34**. A spring **37** as biasing means for the locking member urges the lock piston **30** toward the fitting hole **36**.

Pressure of operation oil applied to piston chambers **40** and **41**, both of which are operative as lock releasing chambers, urges the lock piston **30** to be pulled out of the fitting hole **36**. The lock piston **30**, the fitting hole **36**, the spring **37** and the piston chambers **40** and **41** constitute angular phase locking means. The piston chambers **40** and **41** communicate with a piston oil passage **203** for releasing hydraulic pressure. The lock piston **30** can be inserted into the fitting hole **36** when an angular phase of the vane rotor **15** relative to the housing **10** is at a middle position between the most retard angle position and the most advanced angle position and, in a state that the lock piston **30** is fitted in the fitting hole **36**, rotation of the vane rotor **15** relative to the housing **10** is locked. The middle position at which the lock piston **30** is fitted in the fitting hole **36** is set to a valve timing of the intake valve suitable for engine cranking.

When the vane rotor **15** rotates relatively to the housing **10** toward the retard or advanced angle position beyond the middle position, the lock piston **30** can not be fitted in the fitting hole **36** since the piston **30** is not angularly aligned with the fitting hole **36**.

A communication passage **13***a* formed in the front plate **13** shown in FIG. **1** communicates via an arc shaped communication hole **39** formed in the vane **15***a* with an accommodation hole **38** formed on an opposite side of the fitting hole **36** with respect to the lock piston **30**. The lock piston **30** can move reciprocatingly without receiving any resistance from the operation oil since the communication passage **13***a* is opened to atmosphere.

As shown in FIG. **4**, a restriction piston **44** is accommodated in the vane **15***a* so as to move reciprocatingly in an axial direction of the vane **15***a*. An arc shaped restriction hole **45** is formed to extend within a given angular range in the front plate **13**. The restriction piston **44** can be inserted into the restriction hole **45**. A spring **46** as restriction biasing means urges the piston **44** toward the restriction hole **45**.

Pressure of operation oil applied to piston chambers **48** and **49**, both of which are operative as restriction releasing chambers, urges the restriction piston **44** to be pulled out of the restriction hole **45**. The restriction piston **44**, the restriction hole **45**, the spring **46** and the piston chambers **48** and **49** constitute angular phase restriction means. The piston chambers **48** and **49** communicate with the piston oil passage **203** similarly to the piston chambers **40** and **41**. The operation oil is supplied to the piston chambers **40, 41, 48** and **49** commonly from the same hydraulic pressure source via the same supply route so that moving start timings of the lock and restriction pistons **30** and **44** are generally same. A retard angle side end of the restriction hole **45** corresponds to the middle position where the lock piston **30** is fitted in the fitting hole **36**. Accordingly, the restriction piston **44** abuts on the retard angle side end of the restriction hole **45** in a state that the lock piston **30** is fitted in the fitting hole **36**.

As shown in FIG. **2**, retard angle hydraulic pressure chambers **51, 52, 53** and **54** are formed between the shoe **12***a* and vane **15***a*, between the shoe **12***b* and the vane **15***b*, between the shoe **12***c* and the vane **15***c* and between the shoe **12***d* and the vane **15***d*, respectively. Advanced angle hydraulic chambers **55, 56, 57** and **58** are formed between the shoe **12***d* and vane **15***a*, between the shoe **12***a* and the vane **15***b*, between the shoe **12***b* and the vane **15***c* and between the shoe **12***c* and the vane **15***d*, respectively.

As shown in FIG. **1**, the camshaft **3** is provided on an outer circumferential wall thereof that slides on an inner circumferential wall of the bearing **4** with an advance angle oil passage **202**, a retard angle oil passage **201** and the piston oil passage **203** which are formed in a ring shape and spaced in an axial direction thereof. The retard angle oil passage **201** and the advanced angle oil passage **202** are connected to the spool valve **230** to be driven electro-magnetically via oil passages **205** and **206**, respectively. The piston oil passage **203** is connected to the solenoid valve **240** via an oil passage **207**. A hydraulic pressure supply route through which the operation oil is supplied to the retard angle oil passage **201** and the advanced angle oil passage **202** is different from hydraulic pressure supply route through which the operation oil is supplied to the piston oil passage **203**. In the former route, the operation oil is hydraulically controlled by the spool valve **230** to be driven electro-magnetically and, in the latter route, the operation oil is hydraulically controlled by the solenoid valve **240**.

An oil supply passage **210** is connected to an oil pump **220**. The oil pump **220** is a mechanical pump rotatable with the engine. The oil pump **220** can supply the operation oil drawn up from a drain **221** to the retard angle oil passage **201** and the advanced angle oil passage **202** via the spool valve **230** and to the piston oil passage **203** via the solenoid valve **240**. An oil temperature sensor **250** detects temperature of the operation oil of the oil supply passage **210**.

The spool valve **230** is duty ratio controlled by an electrically control unit (ECU) for the engine (not shown). The spool valve **230** controls hydraulic pressure of the respective retard and advanced angle hydraulic chambers **51** to **54** and **55** to **58** in such a manner that reciprocating movement of a spool (not shown) allows or prohibits the oil passage **205** or the oil passage **206** to communicate with the oil supply passage **210** or the drain **221**.

The solenoid valve is also controlled by ECU. The oil passage **207** communicates with the oil supply passage **210** upon energizing the solenoid valve **240** and is opened to the drain **221** upon de-energizing the solenoid valve **240**.

As shown in FIG. **2**, oil passages **61, 62, 63** and **64** that are formed in the vane rotor **15** communicate with the retard angle oil passage **201** via oil passages formed in the vane rotor **15** and the camshaft **3**. The oil passages **61, 62, 63** and **64** communicate with the retard angle hydraulic chambers **51, 52, 53** and **54**, respectively.

Oil passages **65** and **66** are formed in an end surface of the vane rotor **15** in contact with an axial end of the camshaft **3** and communicates with the advanced angle oil passage **202** via an oil passage **204** formed in the camshaft **3**. The oil passage **65** communicates with the advanced angle hydraulic chambers **56** and **57** and the oil passage **66** communicates with the advanced angle hydraulic chambers **55** and **58**.

With the construction mentioned above, the operation oil from the oil pump **22** can be supplied to the retard angle hydraulic chambers **51, 52, 53** and **54**, the advanced angle hydraulic chambers **55, 56, 57** and **58** and the piston chambers **40, 41, 48** and **49** and the operation oil can be ejected from the respective hydraulic chambers to the drain **221**.

An operation of the valve timing adjusting apparatus **1** is described.

When the solenoid valve **240** is energized at a normal engine operation, the operation oil is supplied to the piston chambers **40, 41, 48** and **49** from the piston oil passage **203**. As shown in FIG. **4**, hydraulic pressures of the piston chambers **40** and **41** cause the lock piston **30** to pull out of the fitting hole **36** against biasing force of the spring **37**. Hydraulic pressures of the piston chambers **48** and **49** cause the restriction piston **44** to pull out of the restriction hole **45** against biasing force of the spring **46**. At this time, the vane rotor **15** is rotatable relatively to the housing **10**. Pressures applied to the respective retard and advanced angle hydraulic chambers are adjusted by a duty ratio control of the spool valve **230** so that angular phase of the camshaft **3** relative to the crankshaft is defined.

When an ignition key is turned on to stop the engine, the engine is generally in an idling operation state. In the idling operation state, the valve timing of the intake valve is set generally to an intermediate position between a middle position and the most retard angle position. Current for driving the spool valve **230** is controlled for a certain period just before the engine stops so as to cause the advanced angle oil passage **202** to communicate with the oil supply passage **210** so that the operation oil is supplied to the respective advanced angle hydraulic chambers. Since the retard angle oil passage **201** is opened to the drain **221**, the operation oil of the respective retard angle hydraulic chambers is ejected via the retard angle oil passage **201**. Accordingly, the vane rotor **15** rotates relatively to the housing **10** toward the middle position from the intermediate position between the middle position and the most retard angle position. Further, when the engine stops, the solenoid valve **240** is de-energized so that the piston oil passage **203** is opened to the drain **221**. Accordingly, the operation oil of the piston chambers **40, 41, 48** and **49** is ejected via the piston oil passage **203**. The lock piston **30** is moved toward the fitting hole **36** by the biasing force of the spring **37** and the restriction piston **44** is moved toward the restriction hole **45** by the biasing force of the spring **46**.

When the vane rotor **15** rotates relatively to the housing **10** to the middle position, the lock piston **30** is fitted in the fitting hole **36** so that the angular phase of the vane rotor **15** relative to the housing **10** is locked.

Retard and advanced angle responsive speed of rotating the vane rotor **15** relatively to the housing **10**, speed of inserting the lock piston **30** into the fitting hole **36** and speed of inserting the restriction piston **44** into the restriction hole **45** are variable according to changes of viscosity of the operation oil, that is, temperature and pressure of the operation oil. For example, as shown in FIG. **5**, as the viscosity of the operation oil decreases with increase of temperature of the operation oil, the pressure of the operation oil decreases so that the retard and advanced angle responsive speed of rotating the vane rotor **15** relatively to the housing **10** becomes slower. Further, as the viscosity of the operation oil decreases with increase of temperature of the operation oil, the operation oil is more easily ejected from the piston chambers **40, 41, 48** and **49** so that moving speed of the lock piston **30** and moving speed of the restriction piston **44** become faster. On the other hand, as the pressure of the operation oil increases, the retard and advanced angle responsive speed becomes faster and the moving speed of the lock piston **30** and the moving speed of the restriction piston **44** become slower. Furthermore, speed of pulling the lock piston **30** out of the fitting hole **36** and speed of pulling the restriction piston **44** out of the restriction hole **45** are also changed according to changes of the temperature and pressure of the operation oil. In any way, the retard and advanced angle responsive speed of rotating the vane rotor relatively to the housing **10** varies inversely with the moving speeds of the lock and restriction pistons **30** and **44** when the temperature and pressure of the operation oil are changed. The moving speeds of the lock and restriction pistons **30** and **44** are substantially same. Further, since the operation oil is supplied to the piston chambers **40, 41, 48** and **49** via the same supply route from the same hydraulic pressure source, start timing of moving the lock piston **30** to be inserted into the fitting hole **36** is substantially same as start timing of moving the restriction piston **44** to be inserted into the restriction hole **45**.

If the spool valve **230** and the solenoid valve **240** are actuated substantially at the same time so that the start timing of moving the lock piston **30** to be inserted into the fitting hole **36** (lock start timing) or the start timing of moving the rock piston **30** to be pulled out of the fitting hole **36** (lock release start timing) is substantially same as the start timing of rotating the vane rotor **15** relatively to the housing **10** to a target position (rotation start timing), it sometimes happens that the lock piston **30** passes the fitting hole **36** before the lock piston **30** is fitted in the fitting hole **36** or the lock piston **30** can not be pulled out of the fitting hole **36** because the lock piston **30** is pressed against an inner wall of the fitting hole **36**.

According to the first embodiment, the lock start timing or the lock release start timing, which is controlled by the solenoid valve **240**, is retard by a given delay time from the rotation start timing, which is controlled by the spool valve **230**. The given delay time is decided with reference to a delay time map by sensor signals representing the temperature and pressure of the operation oil that are input to ECU. As shown in FIGS. **7** and **8**, the given delay time is shorter with increase of the temperature of the operation oil and longer with increase of the pressure of the operation oil. Instead of the sensor signal from the oil temperature sensor **250**, a sensor signal from a water temperature sensor may be used. Further, instead of the sensor signal from a oil pressure sensor, a sensor signal from an engine revolution sensor may be used. The pressure of the operation oil increases with increase of the engine revolution and decreases with decrease of the engine revolution.

FIG. **10** shows a lock control routine for fitting the lock piston **30** in the fitting hole **36**. At Step **300**, it is determined whether or not there exists a lock mode at a time when the engine stops. Unless the lock mode exists, the routine ends. If the lock mode exists, the solenoid valve **240** is de-energized so that, as shown in FIGS. **9**A and **9**B, the lock piston **30** is urged toward the fitting hole **36** at Step **301**. The restriction piston **44** is also urged toward the restriction hole **45** substantially at the same time when the lock piston is urged.

If it is determined that the lock piston **30** can be fitted in the fitting hole **36** without retarding the rotation start timing from the lock start timing, for example, in a case that the angular phase of the vane rotor **15** relative to the housing **10** is at a position in a vicinity of the most retard angle position, that is, if it is determined that delay control for the spool valve **230** is not necessary, the vane rotor **15** is driven relatively to the housing **10** in an advanced angle direction by duty ratio controlling the spool valve **230** at Step **305**.

If it is determined that the delay control is necessary, the given delay time is defined from the delay time map based on input information representing the temperature and pressure of the operation oil at Step **303**. And, if it is determined that the given delay time has lapsed at Step **304**, the routine goes to Step **305** where the vane rotor **15** is driven relatively to the housing **10** in an advanced angle direction by duty ratio controlling the spool valve **230**. Since the lock piston **30** protrudes toward the fitting hole **36**, the lock piston **30** hits on the opening end of the fitting hole **36** on an advanced angle side so that the lock piston is confidently fitted in the fitting hole **36**.

Even if the lock piston **30** passes the fitting hole **36**, the restriction piston **44** hits on the end of the restriction hole **45** on a retard angle side since the vane rotor **15** is returned in retard angle direction by fluctuating torque that the camshaft **3** receives in a retard angle direction. Since the position where the restriction piston **44** hits on the end of the restriction hole on a retard angle side is the middle position, the lock piston **30** is confidently fitted in the the fitting hole **36**.

When the engine is cranked, the lock piston **30** is pulled out of the fitting hole **36** according to a lock release control routine shown in FIG. **12**. At first, it is determined at Step **310** whether or not a target angular phase of the vane rotor **15** relative to the housing **10** is outside a lock position that is the middle position, in another word, a position shifted from the lock position toward the most retard angle position or the most advanced angle position. If the target angular phase is at the lock position, not the position shifted from the lock position toward the most retard angle position or the most advanced angle position, this routine ends without pulling the lock piston **30** out of the fitting hole **36**.

If the target angular phase is at the position shifted from the lock position toward the most retard angle position or the most advanced angle position, the solenoid valve **240** is energized at Step **311** so that the operation oil is supplied to the piston chambers **40, 41, 48** and **49**. Next, the spool valve is duty ratio controlled so as to cause the vane rotor to receive hydraulic pressure in an advance angle direction at Step **312** and decrease the fluctuating torque that the vane rotor **15** receives in a retard angle direction so that the lock piston **30** is easily pulled out of the fitting hole **36**.

Then, the given delay time is defined from the delay time map based on input information representing the temperature and pressure of the operation oil and, if it is determined that the given delay time has lapsed at Step **313**, the target angular phase is set at Step **314** and the vane rotor **15** rotates relatively to the housing **10** to achieve the target angular phase.

According to the first embodiment, the start timing of rotating the vane rotor **15** relative to the housing **10** to the target angular phase is retard by the delay time defined by the temperature and pressure of the operation oil from the lock start timing of inserting the lock piston **30** into the fitting hole **36** or the lock release start timing of pulling the lock piston out of the fitting hole **36**. Since the lock piston is confidently fitted in the fitting hole **36** at the time of the engine stop, the engine can be cranked with timing of the intake valve most suitable for engine cranking, which results in preventing engine cranking failure. Further, the lock piston **30** can be easily pulled out of the fitting hole **36**.

In the first embodiment, the angular phase restriction means constituted by the restriction piston **44**, the restriction hole **45**, the spring **46** and piston chambers **48** and **49** may be omitted.

(Second Embodiment)

A valve timing adjusting apparatus according to a second embodiment is described with reference to FIGS. **13** to **16**. According to the second embodiment, an oil supply route through which operation oil is supplied to the retard angle hydraulic chambers, the advanced angle hydraulic chamber and the piston chambers **40** and **41**, which is controlled by the spool valve **230**, is different from an oil supply route through which operation oil is supplied to the piston chambers **48** and **49**, which is controlled by the solenoid valve **240**.

At a normal engine operation, advanced angle hydraulic pressure is applied to the piston chamber **40** and retard angle hydraulic pressure is applied to the piston chamber **41** so that the rock piston **30** is pulled out of the fitting hole **36**. The advanced angle hydraulic pressure may be applied to the piston chamber **41** and the retard angle hydraulic pressure may be applied to the piston chamber **40**.

For example, in a case of rapidly reducing vehicle speed during a period when the vehicle is running at high and constant speed, it sometimes happens that, if the angular phase control near the most retard angle position is performed, the engine can not be normally operated because a valve overlap angle, that is, an angle by which a valve opening period of the intake valve overlaps with a valve opening period of the exhaust valve, does not meet the engine operating conditions. To prevent the abnormal condition of the engine mentioned above, it is preferable to perform the angular phase control within a range excluding a position near the most retard angle position in such a manner that the restriction piston **44** is urged to protrude into the restriction hole **45** by de-energizing the solenoid valve **240** and the restriction piston **44** is inserted into the restriction hole **45**.

The restriction piston **44** is inserted into the restriction hole **45** according to a control routine shown in FIG. **14**. At Step **320**, it is determined whether or not the restriction piston **44** should be inserted into the restriction hole **45**. Unless it is determined that the restriction piston **44** should be inserted into the restriction hole **45**, this routine ends. If it is determined that the restriction piston **44** should be inserted into the restriction hole **45**, a given delay time is defined from the delay time map based on input information representing the temperature and pressure of the operation oil and it is determined whether or not the given delay time lapsed at Step **321**. If it is determined that the given delay time has lapsed, the vane rotor **15** is controlled to rotate relatively to the housing **10** in a normal way to achieve the target angular phase at Step **322**. Unless it is determined that the given delay time has lapsed, it is determined at Step **323** whether or not the restriction piston **44** is positioned angularly outside the restriction hole **45** in a state that the vane rotor **15** rotates relatively to the housing **10** to achieve the target angular phase. Unless the restriction piston **44** is positioned angularly outside the restriction hole **45**, that is, if the restriction piston **44** is positioned angularly inside the restriction hole **45**, the routine goes to Step **322** where the normal angular phase control is performed.

If the restriction piston **44** is positioned angularly outside the restriction hole **45**, after the vane rotor **15** temporarily rotates relatively to the housing **10** to achieve a tentative target angular phase, as shown in FIGS. **13**A and **13**B, where the restriction piston **44** is positioned angularly inside the restriction hole and in a vicinity of an end of the restriction hole **45** on a retard angle side or on an advanced angle side at Step **324**, the routine goes to Step **321**. Since the vane rotor **15** moves to achieve the tentative target angular phase within the given delay time, the restriction piston **44** can be inserted into the restriction hole **45** without fail within the given delay time, as shown in FIG. **13**C. After the given delay time lapses, the normal angular phase control is performed. At this time, the angular phase is limited within a range defined by the end of the restriction hole **45** on a retard angle side and the other end of the restriction hole **45** on an advanced angle side.

Since, when the target angular phase calculated before the given delay time lapses is at the position where the restriction piston **44** is positioned angularly outside the restriction hole **45**, the vane rotor **15** temporarily rotates relatively to the housing **10** to achieve the tentative target angular phase within the given delay time, time necessary for rotating the vane rotor to the target angular phase after the given delay time lapses is shorter.

FIG. **16** shows a control routine for pulling the restriction piston **44** out of the restriction hole **45** as shown in FIG. **15**A.

At Step **330**, it is determined whether or not the target angular phase is at a position where the restriction piston **44** is outside the restriction hole **45**. If the target angular phase is at a position where the restriction piston **44** is not outside the restriction hole **45** but inside the restriction hole **45**, this routine ends. If the target angular phase is at the position where the restriction piston **44** is outside the restriction hole **45**, the solenoid valve is de-energized at Step **331** for pulling the restriction piston **44** out of the restriction hole **45**. A given delay time is defined from the delay time map based on input information representing the temperature and pressure of the operation oil and it is determined whether or not the given delay time lapsed at Step **332**. If it is determined that the given delay time has lapsed, the vane rotor **15** is controlled to rotate relatively to the housing **10** in a normal way to achieve the target angular phase at Step **333**. Unless it is determined that the given delay time has lapsed, the vane rotor **15** rotate to achieve a tentative target angular phase where the restriction piston **44** is positioned angularly inside the restriction hole **45** and in a vicinity of an end of the restriction hole on a retard angle side or on an advanced angle side at Step **334**. At this time, as shown in FIG. **15**C, the restriction piston **44** can be easily pulled out of the restriction hole **45** since the restriction piston **44** is inside the restriction hole **45** and in a vicinity of the end of the restriction hole on a retard angle side or on an advanced angle side so that the restriction piston **44** is not in contact with inner wall of the restriction hole **45**.

In the second embodiment, the angular phase locking means constituted by the lock piston **30**, the fitting hole **36**, the spring **37** and piston chambers **40** and **41** may be omitted.

In the first and second embodiments, instead of the delay time map from which the given delay time is defined based on the sensor signals representing the temperature of pressure of the operation oil, numerical formula corresponding to the map may be used. The given delay time may be fixed value.

Further, the valve timing adjusting apparatus mentioned above may be applied to the exhaust valve instead of the intake valve or may be applied commonly to both of the intake valve and the exhaust valve.

Furthermore, instead of a structure that a direction in which the lock piston **30** is inserted toward the fitting hole **36** is an axial direction of the vane rotor **15**, the valve timing adjusting apparatus may have a structure that a direction in which the lock piston is inserted toward the fitting hole perpendicularly to the axial direction of the vane rotor. Moreover, the lock piston may be mounted on the housing and the fitting hole may be provided in the vane rotor.

Still further, instead of the chain sprocket through which the rotating drive force of the camshaft is transmitted to the camshaft, a timing pulley or a timing gear may be used for the same purpose. As an alternative, the vane rotor may receive the drive force of the crankshaft and the housing may be rotated together with the camshaft.

Further, instead of the vane type valve timing adjusting apparatus mentioned above, in a valve timing adjusting apparatus in which a drive force transmitting member having a helical spline engagement mechanism is disposed between the drive side rotating member rotatable with the crankshaft and the driven side rotating member rotatable with the camshaft and the angular phase of the driven side rotating member relative to the drive side rotating member is varied by hydraulically moving reciprocatingly the drive force transmitting member, the lock or restriction piston and the angular phase locking or restriction means may be provided.

Further, instead of the timing gear through which drive force of the crankshaft is transmitted to the camshaft, a timing pulley or a chain sprocket may be used.

What is claimed is:

1. A valve timing adjusting apparatus disposed between a drive shaft of an internal combustion engine and a driven shaft causing an opening and closing operation of at least one of an intake valve and an exhaust valve and operative to change an angular phase of the driven shaft relative to the drive shaft so that opening and closing timing of the at least one of an intake valve and an exhaust valve may be varied, comprising:

a drive side rotating member rotatable together with the drive shaft;

a driven side rotating member rotatable together with the driven shaft,

a rotation control pressure chamber operative to rotate the driven side rotating member relative to the drive side rotating member so that angular phase of the driven side rotating member relative to the drive side rotating member is controlled to a target position between the most retard angle position and the most advanced angle position in response to hydraulic pressure applied thereto;

a lock piston provided in one of the driven and drive side rotating members;

a fitting hole provided in the other of the driven and drive side rotating members; and

an angular phase locking pressure chamber operative to execute one of first and second operations when hydraulic pressure is applied thereto and the other of the first and second operations when application of the hydraulic pressure thereto is released, the first operation being to insert the lock piston into the fitting hole so as to lock the angular phase of the driven side rotating member relative to the drive side rotating member to a middle position between the most retard angle position and the most advanced angle position, and the second operation being to pull the lock piston out of the fitting hole so as to release lock of the angular phase of the driven side rotating member relative to the drive side rotating member at the middle position,

wherein a supply route of the hydraulic pressure to the rotation control pressure chamber is different from that to the angular phase locking pressure chamber and, when at least one of the first and second operations is executed, start timing of rotation of the driven side rotating member relative to the drive side rotating member so as to change the angular phase of the driven side rotating member relative to the drive side rotating member to the target position is retard by a given delay time from start timing of execution of the at least one of the first and second operations.

2. A valve timing adjusting apparatus according to claim **1**, wherein the lock piston is provided at an axial end thereof with a tapered portion whose diameter is smaller toward the round hole, the fitting hole is provided at an opening end thereof with a chamfering portion whose diameter is larger toward the piston, and, when the first operation is executed, the given delay time by which the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard from the start timing of execution of the first operation is larger than time required for the tapered portion to pass the chamfering portion after the first operation starts.

3. A valve timing adjusting apparatus according to claim **1**, wherein the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard by a first given delay time from the start timing of execution of the first operation and by a second given delay time from start timing of execution of the second operation.

4. A valve timing adjusting apparatus according to claim **1**, wherein, when the second operation is executed, the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard by the given delay time from the start timing of execution of the second operation.

5. A valve timing adjusting apparatus according to claim **4**, wherein, after the second operation starts, the hydraulic pressure is applied to the rotation control pressure chamber in such a manner that the angular phase of the driven side rotating member relative to the drive side rotating member is kept at the middle position between the most retard angle position and the most advanced angle position or temporarily moved to a position slightly shifted from the middle position toward the advanced angle position before the given delay time lapses.

6. A valve timing adjusting apparatus according to claim **1**, wherein the given delay time by which the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard from the start timing of execution of the at least one of the first and second operations is determined by sensor signals representing pressure and temperature of fluid applied to at least one of the rotation control pressure chamber and the angular phase locking pressure chamber.

7. A valve timing adjusting apparatus according to claim **1**, further comprising:

a restriction piston provided in one of the driven and drive side rotating members;

a restriction hole formed in shape of an arc extending within a given angular range and provided in the other of the driven and drive side rotating members; and an angular phase restriction pressure chamber operative to execute one of third and fourth operations when hydraulic pressure is applied thereto and the other of the third and fourth operations when application of the hydraulic pressure thereto is released, the third operation being to insert the restriction piston into the restriction hole so as to restrict rotation of the driven side rotating member relative to the drive side rotating member within the given angular range and the fourth operation being to pull the restriction piston out of the restriction hole so as to release restriction of rotation of the driven side rotating member relative to the drive side rotating member within the given angular range,

wherein a supply route of the hydraulic pressure to the angular phase restriction pressure chamber is same as that to the angular phase locking pressure chamber, an end of the given angular range is at a position corresponding to the middle position between the most retard angle position and the most advanced angle position and the other end of the given angular range is at a position away from the middle position toward the most advanced angle position and, when the third operation is executed together with the first operation, the restriction piston abuts on the end of the given angular range within the restriction hole.

8. A valve timing adjusting apparatus according to claim **1**, further comprising:

a mechanical pump rotatable together with the engine for supplying the hydraulic pressure via the supply routes to the rotation control pressure chamber and the angular phase locking pressure chamber.

9. A valve timing adjusting apparatus according to claim **1**, wherein one of the driven and drive side rotating members is a housing having an accommodation chamber and the other of the driven and drive side rotating members is a vane rotatable within a defined angular range in the housing and having a partition with which the accommodation chamber is separated into two rooms one of which is a retard angle pressure chamber and the other of which is an advanced angle pressure chamber, whereby the vane is rotated relatively to the housing by controlling the hydraulic pressures applied to the respective retard and advanced angle pressure chambers.

10. A valve timing adjusting apparatus disposed between a drive shaft of an internal combustion engine and a driven shaft causing an opening and closing operation of at least one of an intake valve and an exhaust valve and operative to change an angular phase of the driven shaft relative to the drive shaft so that opening and closing timing of the at least one of an intake valve and an exhaust valve may be varied, comprising:

a drive side rotating member rotatable together with the drive shaft;

a driven side rotating member rotatable together with the driven shaft,

a rotation control pressure chamber operative to rotate the driven side rotating member relative to the drive side rotating member so that angular phase of the driven side rotating member relative to the drive side rotating member is controlled to a target position between the most retard angle position and the most advanced angle position in response to hydraulic pressure applied thereto;

a restriction piston provided in one of the driven and drive side rotating members;

a restriction hole formed in shape of an arc extending within a given angular range and provided in the other of the driven and drive side rotating members, an end of the restriction hole constituting a retard angle side end and the other end thereof constituting an advance angle side end; and

an angular phase restriction pressure chamber operative to execute one of first and second operations when hydraulic pressure is applied thereto and the other of the first and second operations when application of the hydraulic pressure thereto is released, the first operation being to insert the restriction piston into the restriction hole so as to restrict rotation of the driven side rotating member relative to the drive side rotating member within the given angular range and the second operation being to pull the restriction piston out of the restriction hole so as to release restriction of rotation of the driven side rotating member relative to the drive side rotating member within the given angular range,

wherein a supply route of the hydraulic pressure to the rotation control pressure chamber is different from that to the angular phase restriction pressure chamber and, when at least one of the first and second operations is executed, start timing of rotation of the driven side rotating member relative to the drive side rotating member so as to change the angular phase of the driven side rotating member relative to the drive side rotating member to the target position is retard by a given delay time from start timing of execution of the at least one of the first and second operations.

11. A valve timing adjusting apparatus according to claim **10**, wherein, when the first operation is executed, the hydraulic pressure is applied to the rotation control pressure chamber in such a manner that, if the restriction piston is outside the given angular range of the restriction hole, the angular phase of the driven side rotating member relative to the drive side rotating member is temporarily moved to a position slightly inside the given angular range of the restriction hole before the given delay time lapses, whereby, when the driven side rotating member is rotated relatively to the drive side rotating member after the given delay time lapses, the target position of the angular phase of the driven side rotating member relative to the drive side rotating member is restricted within the given angular range since the restriction piston abuts on the retard angle side end or the advanced angle side end.

12. A valve timing adjusting apparatus according to claim **10**, wherein the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard by a first given delay time from the start timing of execution of the first operation and by a second given delay time from start timing of execution of the second operation.

13. A valve timing adjusting apparatus according to claim **10**, wherein, when the second operation is executed, the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard by the given delay time from the start timing of execution of the second operation.

14. A valve timing adjusting apparatus according to claim **13**, wherein, after the second operation starts, the hydraulic pressure is applied to the rotation control pressure chamber in such a manner that, before the given delay time lapses, the angular phase of the driven side rotating member relative to the drive side rotating member is temporarily moved to a position slightly away inward from the retard angle side end or the advanced angle side end of the restriction hole on which the restriction piston abuts so as to pull smoothly the restriction piston out of the restriction hole.

15. A valve timing adjusting apparatus according to claim **10**, wherein the given delay time by which the start timing of rotation of the driven side rotating member relative to the drive side rotating member is retard from the start timing of execution of the at least one of the first and second operations is determined by sensor signals representing pressure and temperature of fluid applied to at least one of the rotation control pressure chamber and the angular phase restriction pressure chamber.

16. A valve timing adjusting apparatus according to claim **10**, further comprising:

a lock piston provided in one of the driven and drive side rotating members;

a fitting hole provided in the other of the driven and drive side rotating members; and

an angular phase locking pressure chamber operative to execute one of third and fourth operations when hydraulic pressure is applied thereto and the other of the third and fourth operations when application of the hydraulic pressure thereto is released, the third operation being to insert the lock piston into the fitting hole so as to lock the angular phase of the driven side rotating member relative to the drive side rotating member to a given position within the given angular range of the restriction hole and the fourth operation being to pull the lock piston out of the fitting hole so as to release lock of the angular phase of the driven side rotating member relative to the drive side rotating member at the given position,

wherein a supply route of the hydraulic pressure to the angular phase locking pressure chamber is same as that to the rotation control pressure chamber.

17. A valve timing adjusting apparatus according to claim **10**, further comprising:

a mechanical pump rotatable together with the engine for supplying the hydraulic pressure via the supply routes to the rotation control pressure chamber and the angular phase restriction pressure chamber.

18. A valve timing adjusting apparatus according to claim **10**, wherein one of the driven and drive side rotating members is a housing having an accommodation chamber and the other of the driven and drive side rotating members is a vane rotatable within a defined angular range in the housing and having a partition with which the accommodation chamber is separated into two rooms one of which is a retard angle pressure chamber and the other of which is an advanced angle pressure chamber, whereby the vane is rotated relatively to the housing by controlling the hydraulic pressures applied to the respective retard and advanced angle pressure chambers.

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